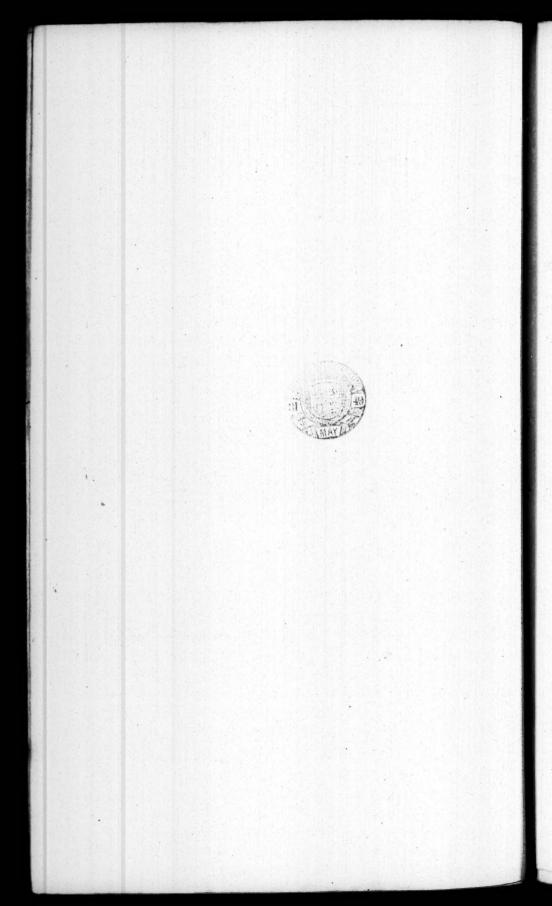
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## LECTURES

ON

SELECT SUBJECTS.



## LECTURES

ON

## SELECT SUBJECTS

IN

MECHANICS,
HYDROSTATICS,
HYDRAULICS,
OPTICS.

WITH

# THE USE OF THE GLOBES, THE ART OF DIALING,

AND

The Calculation of the Mean Times of New and Full Moons and Eclipses.

### By JAMES FERGUSON, F.R.S.



Philosophia mater omnium bonarum artium A.
CICERO. 1. Tusc.

THE EIGHTH EDITION.

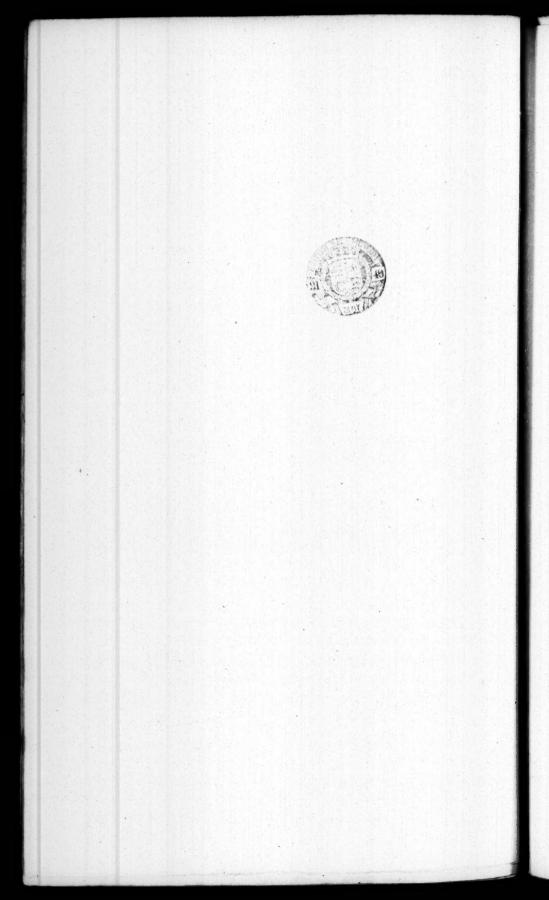
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### ROYAL HIGHNESS

## PRINCE EDWARD.

SIR,

A S Heaven has inspired your ROYAL HIGHNESS with such love of ingenious and useful arts, that you not only study their theory, but have often condescended to honour the professors of mechanical and experimental philosophy with your prefence.

A 3 fence

fence and particular favour; I am thereby encouraged to lay myfelf and the following work at your ROYAL HIGH-NESS'S feet; and at the fame time beg leave to express that veneration with which I am,

SIR,

Your ROYAL HIGHNESS'S

Most obliged,

And most obedient,

Humble Servant,

JAMES FERGUSON.

FVER since the days of the LORD CHAN-CELLOR BACON, natural philosophy hath been more and more cultivated in England. THAT great genius first set out with taking a general survey of all the natural sciences, dividing them into distinct branches, which he enumerated with great exactness. He inquired scrupulously into the degree of knowledge already attained to in each, and drew up a lift of what fill remained to be discovered: this was the scope of his first undertaking. Afterward he carried his views much farther, and showed the necessity of an experimental philosophy, a thing never before thought of. As he was a professed enemy to fystems, he considered philosophy no otherwise than as that part of knowledge which contributes to make men better and happier: he seems to limit it to the knowledge of things useful, recommending above all the study of vature, and shewing that no progress can be nade therein, but by collecting facts, and A 4 com-

comparing experiments, of which he points out a great number proper to be made.

But notwithstanding the true path to science was thus exactly marked out, the old notions of the schools so strongly possessed people's minds at that time, as not to be eradicated by any new opinions, how rationally soever advanced, until the illustrious Mr. Boyle, the first who pursued Lord Bacon's plan, began to put experiments in practice with an assiduity equal to his great talents. Next, the Royal Society being established, the true philosophy began to be the reigning taste of the age, and continues so to this day.

The immortal SIR ISAAC NEWTON infifted, even in his early years, that it was high
time to banish vague conjectures and hypotheses
from natural philosophy, and to bring that
fcience under an entire subjection to experiments and geometry. He frequently called it
the experimental philosophy, so as to express significantly the difference between it and
the numberless systems which had arisen merely
out of the conceits of inventive brains: the
one subsisting no longer than the spirit of novelty

velty lasts; the other never failing while the nature of things remain unchanged.

The method of teaching and laying the foundation of physics, by public courses of experiments, was first undertaken in this kingdom, I believe, by Dr. John Keill, and fince improved and enlarged by Mr. HAUKS-BEE, Dr. DESAGULIERS, Mr. WHISTON. Mr. Cotes, Mr. WHITESIDE, Dr. BRAD-LEY, our late Regius and Savilian Professor of Astronomy, and Dr. Bliss his successor. Nor has the same been ne lected by Dr. JAMES, and Dr. DAVID GREGORY, Sir ROBERT STEWART, and after bim Mr. MACLAURIN. -Dr: HELSHAM in Ireland, Messeurs GRAVESANDE and MUSCHENBROEK, and the Abbé NOLLET in France, have also acquired just applause thereby.

The substance of my own attempt in this way of instrumental instruction, the following sheets (exclusive of the astronomical part) will shew: the satisfaction they have generally given, read as lectures to different audiences, affords me some hope that they may be favourably received in the same sorm by the public.

I ought

I ought to observe, that though the last five lectures cannot be properly said to concern experimental philosophy, I considered, however, that they were not of so different a class, but that they might, without much impropriety, be subjoined to the preceding ones.

My apparatus (part of which is described here, and the rest in a \* former work) is rather simple than magnificent, which is owing to a particular point I had in view at first setting out, namely, to avoid all superstuity, and to render every thing as plain and intelligible as I thought the subject would admit of.

Aftronomy explained upon SIR ISAAC NEWTON'S principles, and made easy to those who have not studied mathematics.

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### LECTURES

ON

## SELECT SUBJECTS.

#### LECT. I.

Of Matter and its Properties.

As the design of the first part of this course is to explain and demonstrate those laws by which the material universe is governed, regulated, and continued; and by which the various appearances in nature are accounted for; it is requisite to begin with explaining the properties of matter.

By the word *matter* is here meant every thing Matter, that has length, breadth, and thickness, and re-what. fifts the touch.

The inherent properties of matter are folidity, Its proinactivity, mobility, and divisibility. perties.

The folidity of matter arises from its having Solidity. length, breadth, thickness; and hence it is that all bodies are comprehended under some shape or other, and that each particular body hinders all others from occupying the same part of space which it possesses. Thus, if a piece of wood or metal be squeezed ever so hard between two plates, they cannot be brought into contact. And even water or air has this property; for if a small quantity of it be fixed between any other bodies.

bodies, they cannot be brought to touch one another.

Inactivity.

A fecond property of matter is *inattivity*, or passivenes; by which it always endeavours to continue in the state that it is in, whether of rest or motion. And therefore, if one body contains twice or thrice as much matter as another body does, it will have twice or thrice as much inactivity; that is, it will require twice or thrice as much force to give it an equal degree of motion, or to stop it after it hath been put into such a motion.

That matter can never put itself into motion is allowed by all men. For they see that a stone, lying on the plane surface of the earth, never removes itself from that place, nor does any one imagine it ever can. But most people are apt to believe that all matter has a propensity to fall from a state of motion into a state of rest; because they see that if a stone or a cannon-ball be put into ever so violent a motion, it soon stops; not considering that this stoppage is caused, 1. By the gravity or weight of the body, which sinks it to the ground in spite of the impulse; and, 2. By the resistance of the air through which it moves, and by which its velocity is retarded every moment till it falls.

A bowl moves but a fhort way upon a bowling-green; because the roughness and unevenness of the grassy surface soon creates friction enough to stop it. But if the green were perfectly level, and covered with polished glass, and the bowl were perfectly hard, round, and smooth, it would go a great way farther; as it would have nothing but the air to resist it; if then the air were taken away, the bowl would go on without any friction, and consequently without

6

any diminution of the velocity it had at fetting out: and therefore, if the green were extended quite around the earth, the bowl would go on,

round and round the earth, for ever.

If the bowl were carried feveral miles above the earth, and there projected in a horizontal direction, with fuch a velocity as would make it move more than a femidiameter of the earth, in the time it would take to fall to the earth by gravity; in that case, and if there were no resisting medium in the way, the bowl would not fall to the earth at all; but would continue to circulate round it, keeping always in the same tract, and returning to the same point from which it was projected, with the same velocity as at first. In this manner the moon goes round the earth, although she be as unactive and dead as any stone upon it.

The third property of matter is *mobility*; for Mobility, we find that all matter is capable of being moved, if a fufficient degree of force be applied to over-

come its inactivity or relistance.

The fourth property of matter is divisibility, Divisibiof which there can be no end. For, fince mat-lityter can never be annihilated by cutting or breaking, we can never imagine it to be cut into such
small particles, but that if one of them be laid
on a table, the uppermost side of it will be further from the table than the undermost side.
Moreover, it would be absurd to say that the
greatest mountain on earth has more halves,
quarters, or tenth parts, than the smallest particle
of matter has.

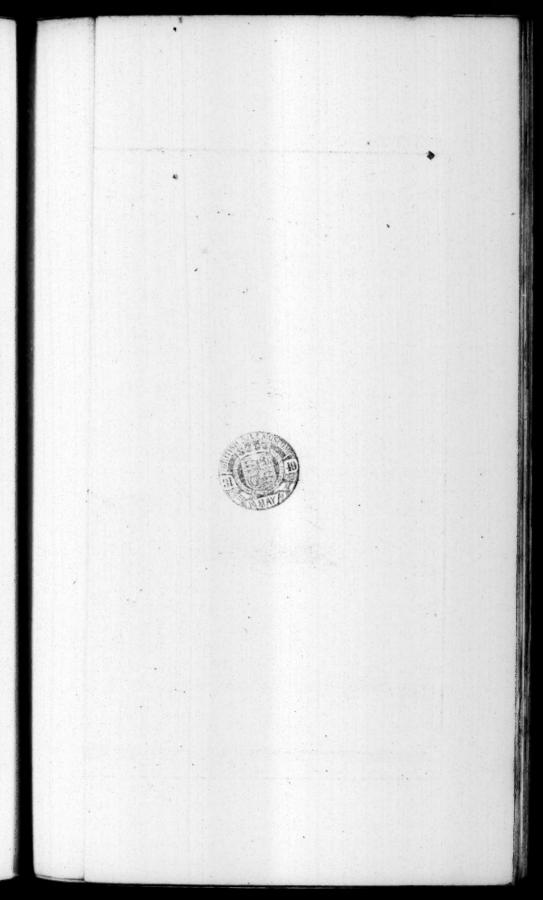
We have many furprifing inftances of the fmallness to which matter can be divided by art: of which the two following are very remarkable.

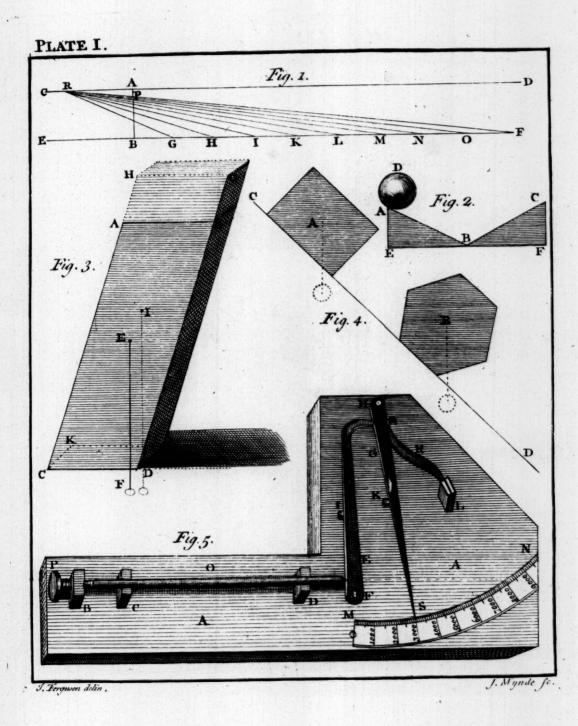
1. If a pound of filver be melted with a fingle grain of gold, the gold will be equally diffused through the whole filver; fo that taking one grain from any part of the mass (in which there can be no more than the 5760 part of a grain of gold) and diffolving it in aqua fortis, the

gold will fall to the bottom.

2. The gold beaters can extend a grain of gold into a leaf containing 50 square inches; and this leaf may be divided into 500000 visible parts, For an inch in length can be divided into 100 parts, every one of which will be visible to the bare eye: confequently a fquare inch can be divided into 10000 parts, and 50 square inches into 500000. And if one of these parts be viewed with a microscope that magnifies the diameter of an object only ten times, it will magnify the area 100 times; and then the 100th part of a 500000th part of a grain (that is, the 50 millionth part) will be visible. Such leaves are commonly used in gilding; and they are so very thin, that if 124500 of them were laid upon one another, and pressed together, they would not exceed one inch in thickness.

Yet all this is nothing in comparison of the lengths that nature goes in the division of mat-For Mr. Leewenboek tells us, that there are more animals in the milt of a fingle cod-fish, than there are men upon the whole earth: and that, by comparing these animals in a microscope with grains of common fand, it appeared that one fingle grain is bigger than four millions Now each animal must have heart, arteries, veins, muscles, and nerves, otherwise they could neither live nor move. How inconceivably small then must the particles of their blood be, to circulate through the smallest ramifications





fications and joinings of their arteries and veins? It has been found by calculation, that a particle of their blood must be as much smaller than a globe of the tenth part of an inch in diameter, as that globe is smaller than the whole earth; and yet, if these particles be compared with the particles of light, they will be found to exceed them as much in bulk as mountains do fingle grains of fand. For, the force of any body striking against an obstacle is directly in proportion to its quantity of matter multiplied into its velocity; and fince the velocity of the particles of light is demonstrated to be at least a million times greater than the velocity of a cannon-ball, it is plain, that if a million of these particles were as big as a fingle grain of fand, we durst no more open our eyes to the light, than we durst expose them to fand shot pointblank from a cannon.

That matter is infinitely divisible in a mathe-Plate I. matical fense, is easy to be demonstrated. For, Fig. 1. let AB be the length of a particle to be divided; and let it be touched at opposite ends by the parallel lines CD and EF, which, suppose to be infinitely extended beyond D and F. Set off The infithe equal divisions BG, GH, HI, &c. on the nite diviline EF, toward the right hand from B; and matter take a point, as at R, any where toward the left proved. hand from A, in the line CD: Then, from this point, draw the right lines RG, RH, RI, &c. each of which will cut off a part from the particle AB. But after any finite number of fuch lines are drawn, there will still remain a part, as AP, at the top of the particle, which can never be cut off: because the lines DR and EF being parallel, no line can ever be drawn from the point R to any point of the line EF that will B 2 coincide

coincide with the line RD. Therefore the particle AB contains more than any finite number

of parts.

Attrac-

A fifth property of matter is attraction, which feems rather to be infused than inherent. Of this there are four kinds, viz. cohesion, gravitation, magnetism, and electricity.

Cohefion.

The attraction of cobesion is that by which the small parts of matter are made to stick and cohere together. Of this we have several instances, some of which follow.

1. If a small glass tube, open at both ends, bedipt in water, the water will rife up in the tube to a confiderable height above its level in the bason: which must be owing to the attraction of a ring of particles of the glass all round in the tube, immediately above those to which the water at any instant rises. And when it has rifen so high, that the weight of the column balances the attraction of the tube, it rifes no higher. This can be no ways owing to the pressure of the air upon the water in the bason; for, as the tube is open at top, it is full of air above the water, which will prefs as much upon the water in the tube as the neighbouring air does upon any column of an equal diameter in the bason. Befides, if the same experiment be made in an exhausted receiver of the air pump, there will be found no difference.

2. A piece of loaf-fugar will draw up a fluid, and a fpunge will draw in water: and on the fame principle fap ascends in trees.

3. If two drops of quickfilver be placed near each other, they will run together and become one large drop.

4. If two pieces of lead be scraped clean, and pressed together with a twist, they will attract

each other so strongly, as to require a force much greater than their own weight to separate them. And this cannot be owing to the pressure of the air, for the same thing will hold in an exhausted receiver.

5. If two polished plates of marble or brass be put together, with a little oil between them to fill up the pores in their surfaces, and prevent the lodgement of any air; they will cohere so strongly, even if suspended in an exhausted receiver, that the weight of the lower plate will not be able to separate it from the upper one. In putting these plates together, the one should be rubbed upon the other, as a joiner does two

pieces of wood when he glues them.

6. If two pieces of cork, equal in weight, be put near each other in a bason of water, they will move equally fast toward each other with an accelerated motion, until they meet: and then, if either of them be moved, it will draw the other after it. If two corks of unequal weights be placed near each other, they will approach with accelerated velocities inversely proportionate to their weights: that is, the lighter cork will move as much faster than the heavier, as the heavier exceeds the lighter in weight. This shews that the attraction of each cork is in direct proportion to its weight or quantity of matter.

This kind of attraction reaches but to a very small distance; for, if two drops of quickfilver be rolled in dust, they will not run together, because the particles of dust keep them out of the

sphere of each other's attraction.

Where the sphere of attraction ends, a repul-Repulfive force begins; thus, water repels most bodies sion. till they are wet; and hence it is, that a small B 3 needle, needle, if dry, fwims upon water; and flies walk

upon it without wetting their feet.

The repelling force of the particles of a fluid is but fmall; and therefore, if a fluid be divided, it easily unites again. But if a glass, or any other hard substance, be broke into small parts, they cannot be made to stick together again without being first wetted: the repulsion being too great to admit of a re-union.

The repelling force between water and oil is fo great, that we find it almost impossible to mix them fo, as not to separate again. If a ball of light wood be dipt in oil, and then put into water, the water will recede so as to form a channel of some depth all around the ball.

The repulsive force of the particles of air is so great, that they can never be brought so near together by condensation as to make them stick or cohere. Hence it is, that when the weight of the incumbent atmosphere is taken off from any small quantity of air, that quantity will diffuse itself so as to occupy (in comparison) an infinitely greater portion of space than it did before.

Gravita-

Attraction of gravitation is that power by which distant bodies tend toward one another. Of this we have daily instances in the falling of bodies to the earth, By this power in the earth it is, that bodies, on whatever fide, fall in lines perpendicular to its furface; and confequently, on opposite sides, they fall in opposite directions; all toward the center, where the force of gravity is as it were accumulated: and by this power it is, that bodies on the earth's furface are kept to it on all fides, fo that they cannot fall from it. And as it acts upon all bodies in proportion to their respective quantities of matter, without any regard to their bulks of figures,

figures, it accordingly constitutes their weight. Hence,

If two bodies which contain equal quantities of matter, were placed at ever fo great a diffance from one another, and then left at liberty in free space; if there were no other bodies in the universe to affect them, they would fall equally swift toward one another by the power of gravity, with velocities accelerated as they approached each other; and would meet in a point which was half-way between them at first. Or, if two bodies, containing unequal quantities of matter, were placed at any diftance, and left in the fame manner at liberty, they would fall toward one another with velocities which would be in an inverse proportion to their respective quantities of matter; and moving faster and faster in their mutual approach, would at last meet in a point as much nearer to the place from which the heavier body began to fall, than to the place from which the lighter body began to fall, as the quantity of matter in the former exceeded that in the latter.

All bodies that we know of have gravity or weight. For, that there is no such thing as positive levity, even in smoke, vapours, and sumes, is demonstrable by experiments on the airpump; which shews, that although the smoke of a candle ascends to the top of a tall receiver when sull of air, yet, upon the air's being exhausted out of the receiver, the smoke falls down to the bottom of it. So, if a piece of wood be immersed in a jar of water, the wood will rise to the top of the water, because it has a less deg of weight than its bulk of water has: but if the jar be emptied of water, the wood falls to the bottom.

Gravity demonftrated to be as the quantity of matter body.

As every particle of matter has its proper gravity, the effect of the whole must be in proportion to the number of the attracting particles; that is, as the quantity of matter in the whole This is demonstrable by experiments on in bodies, pendulums; for, if they are of equal lengths, whatever their weights be, they vibrate in equal Now it is plain, that if one be double or triple the weight of another, it must require a double or triple power of gravity to make it move with the fame celerity: just as it would require a double or triple force to project a bullet of twenty or thirty pounds weight, with the same degree of swiftness that a bullet of ten pounds would require. Hence it is evident, that the power or force of gravity is always proportional to the quantity of matter in bodies, whatever their bulks or figures are.

It deof the distance

Gravity alfo, like all other virtues or emanacreases as tions which proceed or issue from a center, dethe fquare creases as the distance multiplied by itself increases: that is, a body at twice the distance of increases. another, attracts with only a fourth part of the force; at thrice the diffance, with a ninth part; at four times the distance, with a fixteenth part; and fo on. This too is confirmed by comparing the diftance which the moon falls in a minute, from a right line touching her orbit, with the distance through which heavy bodies near the earth fall in that time. And also by comparing the forces which retain Jupiter's moons in their orbits, with their respective distances from Jupi-These forces will be explained in the next lecture.

> The velocity which bodies near the earth acquire in descending freely by the force of gravity, is proportional to the times of their descent.

For,

For, as the power of gravity does not confift in a fingle impulse, but is always operating in a constant and uniform manner, it must produce equal effects in equal times; and consequently in a double or triple time, a double or triple effect. And so, by acting uniformly on the body, must accelerate its motion proportionably to the time of its descent.

To be a little more particular on this subject, let us suppose that a body begins to move with a celerity conftantly and gradually increasing, in fuch a manner, as would carry it through a mile in a minute; at the end of this space it will have acquired fuch a degree of celerity, as is fufficient to carry it two miles the next minute, though it should then receive no new impulse from the cause by which its motion had been accelerated: but if the same accelerating cause continues, it will carry the body a mile farther; on which account, it will have run through four miles at the end of two minutes; and then it will have acquired fuch a degree of celerity, as is fufficient to carry it through a double space in as much more time, or eight miles in two minutes, even though the accelerating force should act upon it no more. But this force still continuing to operate in an uniform manner, will again, in an equal time, produce an equal effect; and fo, by carrying it a mile further, cause it to move through five miles the third minute; for, the celerity already acquired, and the celerity still acquiring, will have each its complete effect. Hence we learn, that if the body should move one mile the first minute, it would move three miles the fecond, five the third, feven the fourth, nine the fifth, and fo on in proportion.

And thus it appears, that the spaces described in fuccessive equal parts of time, by an uniformly accelerated motion, are always as the odd numbers 1, 3, 5, 7, 9, &c. and confequently, the whole spaces are as the squares of the times, or of the last acquired velocities. For, the continued addition of the odd numbers yields the squares of all numbers from unity upward. Thus, 1 is the first odd number, and the square of 1 is 1; 3 is the fecond odd number, and this added to 1 makes 4, the square of 2; 5 is the third odd number, which added to 4 makes 9, the square of 3; and so on for ever. Since, therefore, the times and velocities proceed evenly and conflantly as 1, 2, 3, 4, &c. but the spaces described in each equal times are as 11, 3, 5, 7, &c. it is evident that the space described

In 1 minute will be ---1 = fquare of 1In 2 minutes --1+3 = 4 = fquare of 2In 3 minutes -1+3+5 = 9 = fquare of 3In 4 minutes 1+3+5+7 = 16 = fquare of 4, &c.

N. B. The character + fignifies more, and = equal.

The defeeding velocity will give a power of equal afcent.

As heavy bodies are uniformly accelerated by the power of gravity in their descent, it is plain that they must be uniformly retarded by the same power in their ascent. Therefore, the velocity which a body acquires by falling, is sufficient to carry it up again to the same height from whence it fell: all owance being made for the resistance of the air, or other medium in which the body is moved. Thus, the body D in rolling down the inclined plane AB will acquire such a velocity by the time it arrives at B, as

Fig. 2.

B, as will carry it up the inclined plane BC, almost to C; and would carry it quite up to C, if the body and plane were perfectly smooth, and the air gave no resistance.—So, if a pendulum were put into motion, in a space quite free of air, and all other resistance, and had no friction on the point of suspension, it would move for ever: for the velocity it had acquired in falling through the descending part of the arc, would be still sufficient to carry it equally high in the ascending part thereof.

The center of gravity is that point of a body The cenin which the whole force of its gravity or weight ter of grais united. Therefore, whatever supports that point, bears the weight of the whole body: and while it is supported, the body cannot fall; because all its parts are in a perfect equilibrium

about that point.

An imaginary line drawn from the center of gravity of any body toward the center of the earth, is called the *line of direction*. In this line and line of direction, all heavy bodies descend, if not obstructed.

Since the whole weight of a body is united in its center of gravity, as that center ascends or descends, we must look upon the whole body to do so too. But as it is contrary to the nature of heavy bodies to ascend of their own accord, or not to descend when they are permitted; we may be sure that, unless the center of gravity be supported, the whole body will tumble or sall. Hence it is, that bodies stand upon their bases when the line of direction salls within the base; for in this case the body cannot be made to sall, without first raising the center of gravity higher than it was before. Thus, the inclining body ABCD, whose center of gravity is E, Fig. 3. stands firmly on its base CDIK, because the line

of direction EF falls within the base. But if a weight, as ABGH, be laid upon the top of the body, the center of gravity of the whole body and weight together is raised up to I; and then, as the line of direction ID falls without the base at D, the center of gravity I is not supported; and the whole body and weight tumble

down together.

Hence appears the abfurdity of people's rifing hastily in a coach or boat when it is likely to overset: for, by that means they raise the center of gravity so far as to endanger throwing it quite out of the base; and if they do, they overset the vehicle effectually. Whereas, had they clapt down to the bottom, they would have brought the line of direction, and consequently the center of gravity, farther within the base, and by that means might have saved themselves.

The broader the base is, and the nearer the line of direction is to the middle or center of it, the more firmly does the body fland. On the contrary, the narrower the base, and the nearer the line of direction is to the fide of it, the more eafily may the body be overthrown, a lefs change of polition being sufficient to remove the line of direction out of the base in the latter case than in the former. And hence it is, that a fphere is fo easily rolled upon a horizontal plane; and that it is so difficult, if not impossible, to make things which are sharp-pointed to stand upright on the point.-From what hath been faid, it plainly appears, that if the plane be inclined on which the heavy body is placed, the body will slide down upon the plane while the line of direction falls within the base; but it will tumble or roll down when that line falls without

the base. Thus, the body A will only slide Fig. 4. down the inclined plane CD, while the body B

rolls down upon it.

When the line of direction falls within the base of our feet, we stand; and most firmly when it is in the middle: but when it is out of that base, we immediately fall. And it is not only pleasing, but even surprising, to resect upon the various and unthought-of methods and postures which we use to retain this position, or to recover it when it is lost. For this purpose we bend our body forward when we rise from a chair, or when we go up stairs: and for this purpose a man leans forward when he carries a burden on his back, and backward when he carries it on his breast; and to the right or lest side as he carries it on the opposite side. A thousand more instances might be added.

The quantity of matter in all bodies is in exact proportion to their weights, bulk for bulk. Therefore, heavy bodies are as much more dense or compact than light bodies of the same bulk,

as they exceed them in weight.

All bodies are full of pores, or spaces void of All bomatter: and in gold, which is the heaviest of dies poall known bodies, there is perhaps a greater
quantity of space than of matter. For the particles of heat and magnetism find an easy passage
through the pores of gold; and even water itself
has been forced through them. Besides, if we
consider how easily the rays of light pass through
so folid a body as glass, in all manner of directions, we shall find reason to believe that bodies
are much more porous than is generally imagined.

All bodies are some way or other affected by The exheat; and all metallic bodies are expanded in pansion of length, metals.

length, breadth, and thickness thereby.—The proportion of the expansion of several metals, according to the best experiments I have been able to make with my pyrometer, is nearly thus: Iron and steel, as 3, copper 4 and a half, brass 5, tin 6, lead 7. An iron rod 3 feet long is about one 70th part of an inch longer in summer than in winter.

The py-

The pyrometer here mentioned being (for aught I know) of a new construction, a defcription of it may perhaps be agreeable to the reader.

Fig. 5.

AA is a flat piece of mahogany, in which are fixed four brass stude B, C, D, L; and two pins, one at F and the other at H. On the pin F turns the crooked index E I, and upon the pin H the straight index GK, against which a piece of watch-spring R bears gently, and so presses it toward the beginning of the scale MN, over which the point of that index moves. scale is divided into inches and tenth parts of an inch: the first inch is marked 1000, the second 2000, and so on. A bar of metal O is laid into notches in the top of the studs C and D; one end of the bar bearing against the adjusting fcrew P, and the other end against the crooked index E I, at a 20th part of its length from its centre of motion F.—Now it is plain, that however much the bar O lengthens, it will move that part of the index E I, against which it bears, just as far: but the crooked end of the same index, near H, being 20 times as far from the center of motion  $\tilde{F}$ , as the point is against which the bar bears, it will move 20 times as far as the bar lengthens. And as this crooked end bears against the index GK at only a 20th part of the whole length GS from its center of motion

motion H, the point S will move through 20 times the space that the point of bearing near H does. Hence, as 20 multiplied by 20 produces 400, it is evident that if the bar lengthens but a 400th part of an inch, the point S will move a whole inch on the scale; and as every inch is divided into 10 equal parts, if the bar lengthens but the 10th part of the 400th part of an inch, which is only the 4000th part of an inch, the point S will move the tenth part of an inch,

which is very perceptible.

To find how much a bar lengthens by heat, first lay it cold into the notches of the studs, and turn the adjusting screw P until the spring R brings the point S of the index GK to the beginning of the divisions of the scale at M: then, without altering the screw any farther, take off the bar, and rub it with a dry woollen cloth till it feels warm; and then, laying it on where it was, observe how far it pushes the point S upon the scale by means of the crooked inclex EI; and the point S will shew exactly how much the bar has lengthened by the heat of rubbin 3. the bar cools, the fpring R bearing against the index KG, will cause its point S to move gradually back toward M in the scale: and when the bar is quite cold, the index will rest at M, where it was before the bar was made warrn by rubbing, The indexes have small rollers under them at I and K; which, by turning round on the smooth wood as the indexes move, make their motions the easier, by taking off a great part of the friction, which would otherwise be on the pins F and H, and of the points of the indexes themselves on the wood.

Beside the universal properties above men-Magnettioned, there are bodies which have properties ism. peculiar to themselves: such as the loadstone, in which the most remarkable are these: 1. It attracts iron and steel only. 2. It constantly turns one of its sides to the north and another to the south, when suspended by a thread that does not twist. 3. It communicates all its properties to a piece of steel when rubbed upon it, without

losing any itself.

According to Dr. Helsham's experiments, the attraction of the loadstone decreases as the square of the distance increases. Thus, if a loadstone be suspended at one end of a balance, and counterpoifed by weights at the other end, and a flat piece of iron be placed beneath it, at the distance of four tenths of an inch, the stone will immediately defcend and adhere to the iron. But if the stone be again removed to the same distance, and as many grains be put into the scale at the other end as will exactly counterbalance the attraction, then, if the iron be brought twice as near the stone as before, that is, only two tenth parts of an inch from it, there must be four times as many grains put into the scale as before, in order to be a just counterbalance to the attractive force, or to hinder the stone from descending and adhering to the iron. So, if four grains will do in the former case, there must be fixteen in the latter. But from fome later experiments, made with the greatest accuracy, it is found that the force of magnetism decreases in a ratio between the reciprocal of the square and the reciprocal of the cube of the distance; approaching to the one or the other, as the magnitudes of the attracting bodies are varied.

Several bodies, particularly amber, glass, jet, fealing-wax, agate, and almost all precious stones, have a peculiar property of attracting and

Electri-

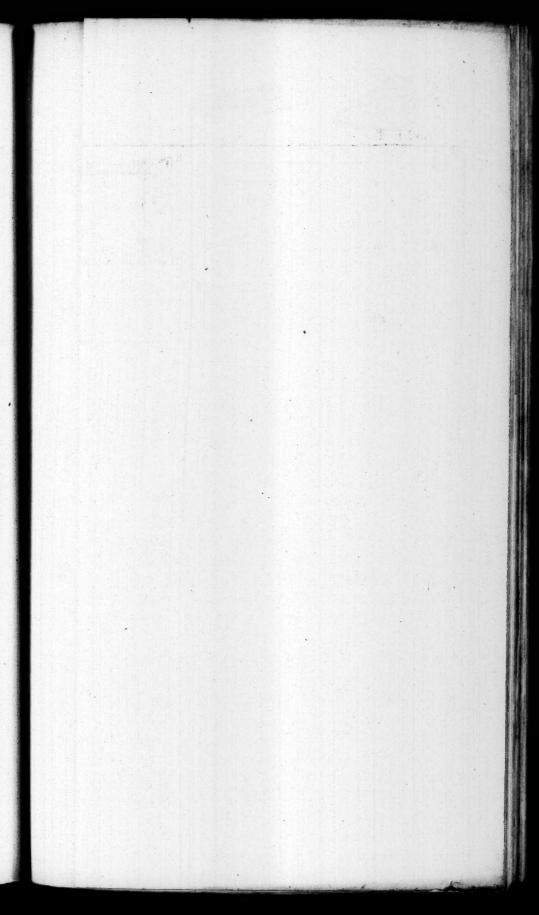
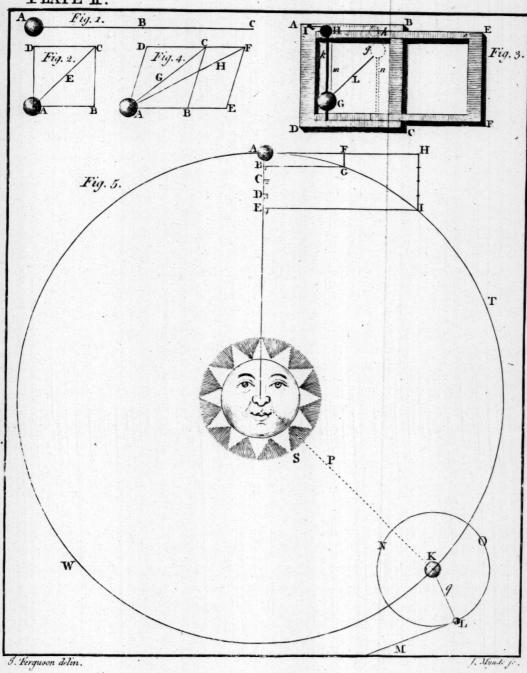


PLATE II.



and repelling light bodies when heated by rub-This is called electrical attraction, in bing. which the chief things to be observed are, 1. If a glass tube about an inch and a half diameter, and two or three feet long, be heated by rubbing, it will alternately attract and repel all light bodies when held near them. 2. It does not attract by being heated without rubbing. 3. Any light body, being once repelled by the tube, will never be attracted again till it has touched some other body. 4. If the tube be rubbed by a moist hand, or any thing that is wet, it totally destroys the electricity. 5. Any. body, except air, being interposed, stops the electricity. 6. The tube attracts stronger when rubbed over with bees-wax, and then with a dry woollen-cloth. 7. When it is well rubbed, if a finger be brought near it, at about the distance of half an inch, the effluvia will fnap against the finger, and make a little crackling noise; and if this be performed in a dark place, there will appear a little flash of light.

## LECT. II.

## Of central Forces.

WE have already mentioned it as a neces-All bodies fary consequence arising from the dead-equally ness or inactivity of matter, that all bodies indifferent to endeavour to continue in the state they are in, motion or whether of rest or motion. If the body A were rest. placed in any part of free space, and nothing Plate II. either drew or impelled it any way, it would for ever remain in that part of space, because it could have no tendency of itself to remove any way from thence. If it receives a fingle impulle

pulse any way, as suppose from A toward B, it will go on in that direction; for, of itself, it could never swerve from a right line, nor stop its course.—When it has gone through the space AB, and met with no resistance, its velocity will be the same at B as it was at A; and this velocity, in as much more time, will carry it through as much more space, from B to C; and B on for ever. Therefore, when we see a body in motion, we conclude that some other substance must have given it that motion; and when we see a body fall from motion to rest, we conclude that some other body or cause stopt it.

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All motion naturally rectilineal.

As all motion is naturally rectilineal, it appears, that a bullet projected by the hand, or that from a cannon, would for ever continue to move in the same direction it received at first, if no other power diverted its course. when we fee a body move in a curve of any kind whatever, we conclude it must be acted upon by two powers at least; one putting it in motion, and another drawing it off from the rectilineal course it would otherwise have continued to move in: and whenever that power, which bent the motion of the body from a straight line into a curve, ceases to act, the body will again move on in a straight line touching that point of the curve in which it was when the action of that power ceased. For example, a pebble moved round in a fling ever fo long a time, will fly off the moment it is fet at liberty, by flipping one end of the fling cord: and will go on in a line touching the circle it described before: which line would actually be a straight one, if the earth's attraction did not affect the pebble, and bring it down to the ground. This shews that the natural tendency of the pebble, when put

into motion, is to continue moving in a straight line, although by the force that moves the sling it be made to revolve in a circle.

The change of motion produced is in propor- The eftion to the force impressed: for the effects of fects of natural causes are always proportionate to the forces.

force or power of those causes.

By these laws it is easy to prove that a body will describe the diagonal of a square or parallelogram, by two forces conjoined, in the fame time that it would describe either of the fides, by one force fingly. Thus, suppose the body A to represent a ship at sea; and that it is Fig. 2. driven by the wind, in the right line AB, with fuch a force as would carry it uniformly from A to B in a minute: then suppose a stream or current of water running in the direction AD, with fuch a force as would carry the ship through an equal space from A to D in a minute. By these two forces, acting together at right angles to each other, the ship will describe the line AEC in a minute: which line (because the forces are equal and perpendicular to each other) will be the diagonal of an exact square. To confirm this law by an experiment, let there be a wooden square ABCD so contrived, as to have the part Fig. 3. BEFC made to draw out or push into the square at pleasure. To this part let the pulley H be joined, fo as to turn freely on an axis, which will be at H when the piece is pushed in, and To this part let the at b when it is drawn out. ends of a straight wire k be fixed, so as to move along with it, under the pulley; and let the ball G be made to slide easily on the wire. A thread m is fixed to this ball, and goes over the pulley to I; by this thread the ball may be drawn up on the wire, parallel to the fide AD, when the

part BEFC is pushed as far as it will go into the square. But, if this part be drawn out, it will carry the ball along with it, parallel to the bottom of the square D C. By this means, the ball G may either be drawn perpendicularly upward by pulling the thread m, or moved horizontally along by pulling out the part BEFC, in equal times, and through equal spaces; each power acting equally and feparately upon it. But if, when the ball is at G, the upper end of the thread be tied to the pin I, in the corner A of the fixed fquare, and the moveable part BEFC be drawn out, the ball will then be acted upon by both the powers together: for it will be drawn up by the thread toward the top of the square, and at the same time be carried with its wire k toward the right hand BC, moving all the while in the diagonal line L; and will be found at g when the fliding part is drawn out as far as it was before; which then will have caused the thread to draw up the bail to the top of the infide of the square, just as high as it was before, when drawn up fingly by the thread without moving the fliding part.

If the acting forces are equal, but at oblique angles to each other, fo will the fides of the parallelogram be: and the diagonal run through by the moving body will be longer or fhorter, according as the obliquity is greater or smaller. Thus, if two equal forces act conjointly upon the body A, one having a tendency to move it through the space AB in the same time that the other has a tendency to move it through an equal space AD; it will describe the diagonal AGC in the same time that either of the single forces would have caused it to describe either of the sides. If one of the forces be greater than the other,

Fig. 4.

other, then one fide of the parallelogram will be fo much longer than the other. For, if one force fingly would carry the body through the space AE, in the fame time that the other would have carried it through the space AD, the joint action of both will carry it in the fame time through the space AHF, which is the diagonal of the

oblique parallelogram ADEF.

If both forces act upon the body in fuch a manner, as to move it uniformly, the diagonal described will be a straight line; but if one of the forces acts in fuch a manner as to make the body move faster and faster, then the line described will be a curve. And this is the case of all bodies which are projected in rectilineal directions, and at the same time acted upon by the power of gravity; which has a constant tendency to accelerate their motions in the direction wherein it acts.

From the uniform projectile motion of bodies The laws in straight lines, and the universal power of gravity of the or attraction, arises the curvilineal motion of all motions. the heavenly bodies. If the body A be projected along the straight line AFH in open space, Fig. 5. where it meets with no refistance, and is not drawn afide by any power, it will go on for ever with the fame velocity, and in the fame direction. But if, at the same moment the projectile force is given it at A, the body 8 begins to attract it with a force duly adjusted \*, and perpendicular to its motion at A, it will then be drawn from the straight line AFH, and forced

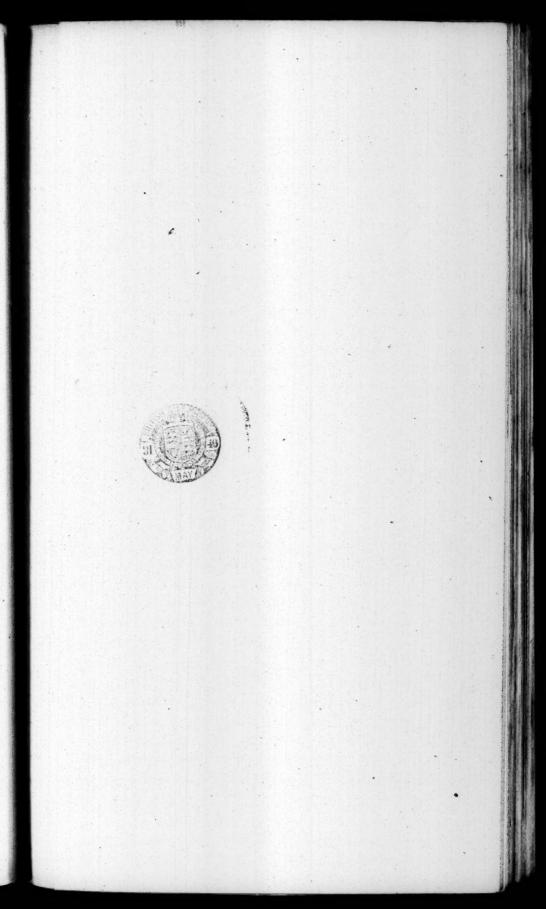
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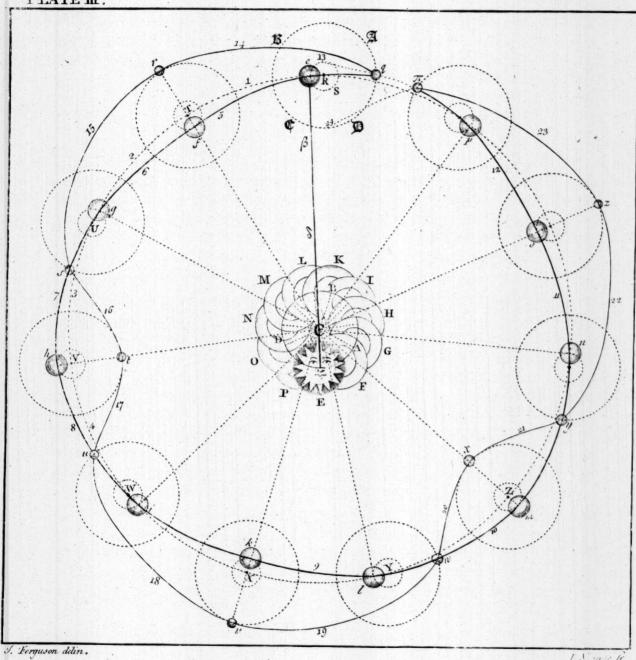
to

<sup>\*</sup> To make the projectile force a just balance to the gravitating power, fo as to keep the planet moving in a circle, it must give such a velocity as the planet would acquire by gravity, when it had fallen through half the femidiameter of that circle,

to revolve about S in the circle ATW; in the fame manner, and by the fame law, that a pebble is moved round in a fling. And if, when the body is in any part of its orbit (as suppose at K) a smaller body as L, within the sphere of attraction of the body K, be projected in the right line LM, with a force duly adjusted, and perpendicular to the line of attraction LK; then, the finall body L will revolve about the large body K in the orbit NO, and accompany it in its whole course round the yet larger body S. But then, the body K will no longer move in the circle ATW; for that circle will now be described by the common center of gravity between K and L. Nay, even the great body S will not keep in the center; for it will be the common center of gravity between all the three bodies S, K, and L, that will remain immoveable there. So, if we suppose S and K connected by a wire P that has no weight, and K and L connected by a wire q that has no weight, the common center of gravity of all these three bodies will be a point in the wire P near S; which point being supported, the bodies will be all in equilibrio as they move round it. Though indeed, strictly speaking, the common center of gravity of all the three bodies will not be in the wire P but when these bodies are all in the right line. Here S may represent the fun, K the earth, and L the moon.

In order to form an idea of the curves defcribed by two bodies revolving about their common center of gravity, while they themselves with a third body are in motion round the common center of gravity of all the three; let Plate III, us first suppose E to be the sun, and e the earth going round him without any moon; and their





their moving forces regulated as above. In this case, while the earth goes round the sun in the dotted circle RTUWX, &c. the sun will The go round the circle ABD, whose center C is curves desired the common center of gravity between the sun foribed by and earth: the right line  $\beta$  representing the volving mutual attraction between them, by which they about are as firmly connected as if they were fixed at their the two ends of an iron bar strong enough to center of hold them. So, when the earth is at e, the sun will be at e; when the earth is at e, the sun will be at e; and when the earth is at e, the sun will be at e, &c.

Now, let us take in the moon q (at the top of the figure) and suppose the earth to have no progressive motion about the sun; in which case, while the moon revolves about the earth in her orbit ABD , the earth will revolve in the circle S 13, whose center R is the common center of gravity of the earth and moon; they being connected by the mutual attraction between them in the same manner as the earth and sun are.

But the truth is, that while the moon revolves about the earth, the earth is in motion about the fun; and now, the moon will cause the earth to describe an irregular curve, and not a true circle, round the sun; it being the common center of gravity of the earth and moon that will then describe the same circle which the earth would have moved in, if it had not been attended by a moon. For, supposing the moon to describe a quarter of her progressive orbit about the earth in the time that the earth moves from e to f; it is plain, that when the earth comes to f, the moon will be found at r; in which time, their common center of gravity

will have described the dotted arc R 1 T, the earth the curve R 5 f, and the moon the curve f 14 f. In the time that the moon describes another quarter of her orbit, the center of gravity of the earth and moon will describe the dotted arc f 2 f 2, the earth the curve f 6 f 3, the moon the curve f 15 f 3, and so on—And thus, while the moon goes once round the earth in her progressive orbit, their common center of gravity describes the regular portion of a circle f 1 f 2 f 3 f 4 f 4, the earth the irregular curve f 5 f 6 f 7 f 8 f 3, and the moon the yet more irregular curve f 14 f 15 f 16 f 17 f 13 and then, the same kind of tracks over again.

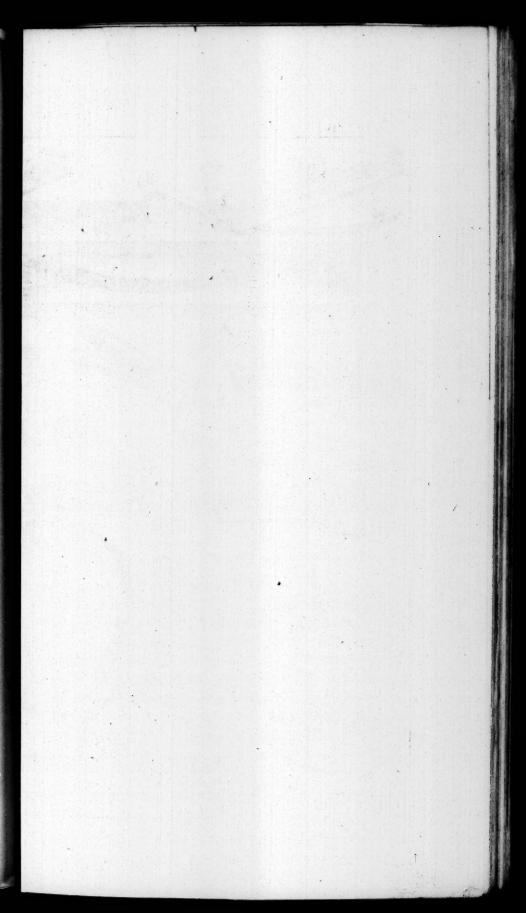
The center of gravity of the earth and moon is 6000 miles from the earth's center toward the moon; therefore the circle S 13 which the earth describes round that center of gravity (in every course of the moon round her orbit) is 12,000 miles in diameter. Consequently the earth is 12,000 miles nearer the sun at the time of sul moon than at the time of new. See the earth

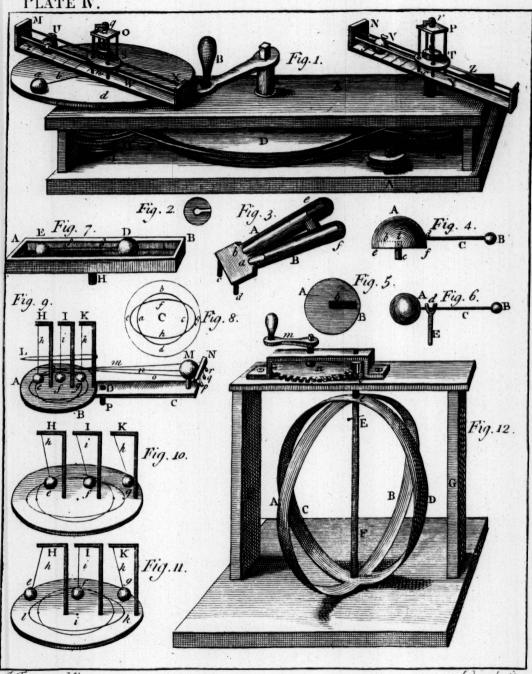
at f and at b.]

To avoid confusion in so small a figure, we have supposed the moon to go only twice and a half round the earth, in the time that the earth goes once round the sun: it being impossible to take in all the revolutions which she makes in a year, and to give a true figure of her path, unless we should make the semidiameter of the earth's orbit at least 95 inches; and then, the proportional semidiameter of the moon's orbit would be only a quarter of an inch.—For a true figure of the moon's path, I refer the reader to my treatise of astronomy.

If the moon made any complete number of revolutions about the earth, in the time that the

earth





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earth makes one revolution about the fun, the paths of the fun and moon would return into themselves at the end of every year; and so be the same over again; but they return not into themselves in less than 19 years nearly; in which time, the earth makes nearly 19 revolutions about the sun, and the moon 235 about the earth.

If the planet A be attracted toward the fun, Plate II. with fuch a force as would make it fall from A Fig. 5. to B, in the time that the projectile impulse would have carried it from A to F, it will describe the arc AG by the combined action of these A double forces, in the same time that the former would projectile have caused it to fall from A to B, or the latter force bahave carried it from A to F. But, if the projec-quadruple tile force had been twice as great, that is, fuch as power of would have carried the planet from A to H, in gravity. the fame time that now, by the supposition, it carries it only from A to F; the fun's attraction must then have been four times as strong as formerly, to have kept the planet in the circle ATW; that is, it must have been such as would have caused the planet to fall from A to E, which is four times the diffance of A from B, in the time that the projectile force fingly would have carried it from A to H, which is only twice the distance of A from  $F^*$ . Thus, a double projectile force will balance a quadruple power of gravity in the fame circle; as appears plain by the figure, and shall foon be confirmed by an experiment.

The whirling-table is a machine contrived Plate IV. for shewing experiments of this nature. AA is Fig. 1. a strong frame of wood, B a winch or handle

fixed

<sup>\*</sup> Here the arcs AG, AI, must be supposed to be very small; otherwise AE, which is equal to HI, will be more than quadruple to AB, which is equal to FG.

The whirling table defcribed. fixed on the axis C of the wheel D, round which is the catgut string F, which also goes round the small wheels G and K, crossing between them and the great wheel D. On the upper end of the axis of the wheel G, above the frame, is sixed the round board d, to which the bearer MSX may be saftened occasionally, and removed when it is not wanted. On the axis of the wheel H is sixed the bearer NTZ: and it is easy to see that when the winch B is turned, the wheels and bearers are put into a whirling motion.

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Each bearer has two wires, W, X, and Y, Z, fixed and screwed tight into them at the ends by nuts on the outside. And when these nuts are unscrewed, the wires may be drawn out in order to change the balls U and V, which flide upon the wires by means of brafs loops fixed into the balls, which keep the balls up from touching the wood below them. A ftrong filk line goes through each ball, and is fixed to it at any length from the center of the bearer to its end, as occasion requires, by a nut-screw at the top of the ball; the shank of the screw goes into the center of the ball, and presses the line against the under fide of the hole that it goes through. -The line goes from the ball, and under a small pulley fixt in the middle of the bearer; then up through a focket in the round plate (fee S and T) in the middle of each bearer; then through a flit in the middle of the square top (O and P) of each tower, and going over a fmall pulley on the top, comes down again the fame way, and is at last fastened to the upper end of the socket fixt in the middle of the above-mentioned round plate. These plates S and T have each four round holes near their edges for letting them flide

flide up and down upon the wires which make the corners of each tower. The balls and plates being thus connected, each by its particular line, it is plain, that if the balls be drawn outward, or toward the ends M and N of their respective bearers, the round plates S and T will be drawn up to the top of their respective towers O and P.

There are several brass weights, some of two ounces, some of three, and some of sour, to be occasionally put within the towers O and P, upon the round plates S and T: each weight having a round hole in the middle of it, for going upon the sockets or axes of the plates, and is slit from the edge to the hole, for allowing it to be slipt over the aforesaid line which comes from each ball to its respective plate. (See Fig. 2.)

The experiments to be made by this machine

are as follows:

1. Take away the bearer MX, and take the Fig. 1. ivory ball a, to which the line or filk cord b is fastened at one end; and having made a loop on the other end of the cord, put the loop over a Then, The propin fixt in the center of the board d. turning the winch B to give the board a whirling penfity of motion, you will fee that the ball does not imme-matter to diately begin to move with the board, but, on flate it is account of its inactivity, it endeavours to con-in. tinue in the state of rest which it was in before.— Continue turning, until the board communicates an equal degree of motion with its own to the ball, and then turning on, you will perceive that the ball will remain upon one part of the board, keeping the fame velocity with it, and having no relative motion upon it, as is the case with every thing that lies loofe upon the plane furface of the earth, which, having the motion of the earth communicated to it, never endeavours to remove from

from that place. But stop the board suddenly by hand, and the ball will go on, and continue to revolve upon the board, until the friction thereof stops its motion: which shews, that matter being once put into motion would continue to move for ever, if it met with no resistance. In like manner, if a person stands upright in a boat before it begins to move, he can fland firm; but the moment the boat fets off, he is in danger of falling toward that place which the boat departs from: because, as matter, he has no natural propenfity to move. when he acquires the motion of the boat, let it be ever fo fwift, if it be fmooth and uniform, he will fland as upright and firm as if he was on the plain shore; and if the boat strikes against any obstacle, he will fall toward that obstacle; on account of the propensity he has, as matter, to keep the motion which the boat has put him into.

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2. Take away this ball, and put a longer cord to it, which may be put down through the hollow axis of the bearer MX, and wheel G, and fix a weight to the end of the cord below the machine; which weight, if left at liberty, will draw the ball from the edge of the whirlingboard to its center.

Bodies moving in orbits

have a tendency to fly out of thefe erbits.

Draw off the ball a little from the center, and turn the winch; then the ball will go round and round with the board, and will gradually fly off farther and farther from the center, and raise up the weight below the machine: which shews that all bodies revolving in circles have a tendency to fly off from these circles, and must have fome power acting upon them from the center of motion, to keep them from flying off. machine, and the ball will continue to revolve for

for some time upon the board; but as the friction gradually stops its motion, the weight acting upon it will bring it nearer and nearer to the center in every revolution, until it brings it quite thither. This shews, that if the planets met with any resistance in going round the sun, its attractive power would bring them nearer and nearer to it in every revolution, until they

fell upon it.

3. Take hold of the cord below the machine Bodies with one hand, and with the other throw the ball move upon the round board as it were at right angles faster in to the cord, by which means it will go round bits than and round upon the board. Then observing in large with what velocity it moves, pull the cord be-ones. low the machine, which will bring the ball nearer to the center of the board, and you will see that the nearer the ball is drawn to the center, the safter it will revolve; as those planets which are nearest the sun revolve faster than those which are more remote; and not only go round sooner, because they describe smaller circles, but even move faster in every part of their respective circles.

4. Take away this ball, and apply the bearer Their MX, whose center of motion is in its middle at centrisuw, directly over the center of the whirling-board sal forces d. Then put two balls (V and U) of equal weights upon their bearing wires, and having fixed them at equal distances from their respective centers of motion w and x upon their filk cords, by the screw nuts, put equal weights in the towers O and P. Lastly, put the catgut strings E and F upon the grooves G and H of the small wheels, which being of equal diameters, will give equal velocities to the bearers above, when the winch B is turned: and the balls U and V will

fly

fly off toward M and N; and will raise the weights in the towers at the same instant. This shews, that when bodies of equal quantities of matter revolve in equal circles with equal velo-

cities, their centrifugal forces are equal.

5. Take away these equal balls, and instead of them put a ball of fix ounces into the bearer MX, at a fixth part of the distance w z from the center, and put a ball of one ounce into the opposite bearer, at the whole distance x y, which is equal to w z from the center of the bearer; and fix the balls at these distances on their cords. by the screw nuts at top; and then the ball  $U_i$ which is fix times as heavy as the ball V, will be at only a fixth part of the distance from its center of motion; and confequently will revolve in a circle of only a fixth part of the circumference of the circle in which V revolves. Now, let any equal weights be put into the towers, and the machine be turned by the winch; which (as the catgut string is on equal wheels below) will cause the balls to revolve in equal times; but Vwill move fix times as fast as U, because it revolves in a circle of fix times its radius; and both the weights in the towers will rife at once. This shews, that the centrifugal forces of revolving bodies (or their tendencies to fly off from the circles they describe) are in direct proportion to their quantities of matter multiplied into their respective velocities; or into their distances from the centers of their respective circles. For, supposing U, which weighs fix ounces, to be two inches from its center of motion w, the weight multiplied by the distance is 12: and supposing V, which weighs only one ounce, to be 12 inches distant from the center of motion x, the weight 1 ounce multiplied by the distance 12 inches

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is 12. And as they revolve in equal times, their velocities are as their distances from the center,

namely, as I to 6.

If these two balls be fixed at equal distances from their respective centers of motion, they will move with equal velocities; and if the tower O has 6 times as much weight put into it as the tower P has, the balls will raise their weights exactly at the same moment. This shews that the ball U being six times as heavy as the ball V, has six times as much centrifugal force, in describing an equal circle with an equal

velocity.

6. If bodies of equal weights revolve in equal A double circles with unequal velocities, their centrifugal velocity forces are as the squares of the velocities. To in the fame cirprove this law by an experiment, let two balls cle, is a U and V of equal weights be fixed on their cords balance at equal distances from their respective centers to a quaof motion w and x; and then let the catgut power of string E be put round the wheel K (whose cir-gravity. cumference is only one half of the circumference of the wheel H or G) and over the pulley s to keep it tight; and let four times as much weight be put into the tower P, as in the tower O. Then turn the winch B, and the ball V will revolve twice as fast as the ball U in a circle of the fame diameter, because they are equidistant from the centers of the circles in which they revolve; and the weight in the towers will both rife at the fame instant, which shews that a double velocity in the fame circle will exactly balance a quadruple power of attraction in the center of the circle. For the weights in the towers may be considered as the attractive forces in the centers, acting upon the revolving balls; which moving

moving in equal circles, is the fame thing as if they both moved in one and the fame circle.

Kepler's problem.

7. If bodies of equal weights revolve in unequal circles, in fuch a manner that the fquares of the times of their going round are as the cubes of their distances from the centers of the circles they describe; their centrifugal forces are inversely as the squares of their distances from those centers. For, the catgut string remaining as in the last experiment, let the distance of the ball V from the center x be made equal to two of the cross divisions on its bearer; and the diftance of the ball U from the center w be three and a fixth part; the balls themselves being of equal weights, and V making two revolutions by turning the winch, in the time that U makes one: To that if we suppose the ball V to revolve in one fecond, the ball U will revolve in two feconds, the squares of which are one and four: for the square of 1 is only 1, and the square of 2 is 4; therefore the square of the period or revolution of the ball V, is contained four times in the square of the period of the ball U. But the distance of V is 2, the cube of which is 8, and the distance of U is 3, the cube of which is 32 very nearly, in which 8 is contained four times; and therefore, the squares of the periods of V and U are to one another as the cubes of their diffances from x and w, which are the centers of their respective circles. And if the weight in the tower O be four ounces, equal to the square of 2, the distance of V from the center x; and the weight in the tower P be ten ounces, nearly equal to the square of 3th, the diftance of U from w; it will be found upon turning the machine by the winch, that the balls U and V will raise their respective weights at the

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the same instant of time. Which confirms that famous observation of Kepler, viz. That the squares of the times in which the planets go round the sun are in the same proportion as the cubes of their distances from him; and that the sun's attraction is inversely as the square of the distance from his center: that is, at twice the distance, his attraction is four times less; at thrice the distance, nine times less; at four times the distance, sixteen times less; and so on, to the re-

motest part of the system.

8. Take off the catgut string E from the great wheel D and the small wheel H, and let the string F remain upon the wheels D and G. Take away also the bearer MX from the whirling-board d, and instead thereof put the machine AB upon it, fixing this machine to the center of the board by the pins c and d, in fuch Fig. 3. a manner, that the end e f may rife above the board to an angle of 30 or 40 degrees. In the The abupper fide of this machine are two glass tubes furdity of and b, close stopt at both ends; and each tesian vortube is about three quarters full of water. In texes. the tube a is a little quickfilver, which naturally falls down to the end a in the water, because it is heavier than its bulk of water; and in the tube b is a small cork which floats on the top of the water at e, because it is lighter; and it is imall enough to have liberty to rife or fall in the tube. While the board b with this machine upon it continues at rest, the quickfilver lies at the bottom of the tube a, and the cork floats on the water near the top of the tube b. But, upon turning the winch, and putting the machine in motion, the contents of each tube will ly off toward the uppermost ends (which are arthest from the center of motion) the heaviest

with the greatest force. Therefore the quickfilver in the tube a will fly off quite to the end f, and occupy its bulk of space there, excluding the water from that place, because it is lighter than quicksilver; but the water in the tube bflying off to its higher end e, will exclude the cork from that place, and cause the cork to descend toward the lowermost end of the tube, where it will remain upon the lowest end of the water near b; for the heavier body having the greater centrifugal force, will therefore possess the uppermost part of the tube; and the lighter body will keep between the heavier and the lowermost part.

This demonstrates the absurdity of the Carte-sian dostrine of the planets moving round the sun in vortexes: for, if the planet be more dense or heavy than its bulk of the vortex, it will sty off therein, farther and farther from the sun; if less dense, it will come down to the lowest part of the vortex, at the sun: and the whole vortex itself must be surrounded with something like a great wall, otherwise it would sty quite off, planets and all together.—But while gravity exists, there is no occasion for such vortexes; and when it ceases to exist, a stone thrown upward

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will never return to the earth again.

9. If a body be so placed on the whirling-board of the machine (Fig. 1.) that the center of gravity of the body be directly over the center of the board, and the board be put into ever so rapid a motion by the winch B, the body will turn round with the board, but will not remove from the middle of it; for, as all parts of the body are in equilibrio round its center of gravity, and the center of gravity is at rest in the center of motion, the centrifugal force of all parts of the

If one body moves round another, both of them must move round their common center of gravity.

the body will be equal at equal distances from its center of motion, and therefore the body will remain in its place. But if the center of gravity be placed ever so little out of the center of motion, and the machine be turned fwiftly round, the body will fly off toward that fide of the board on which its center of gravity lies. Thus, Fig. 4. if the wire C with its little ball B be taken away from the demi-globe A, and the flat fide e f of this demi-globe be laid upon the whirling-board of the machine, fo that their centers may coincide; if then the board be turned ever fo quick by the winch, the demi-globe will remain where it was placed. But if the wire C be screwed into the demi-globe at d, the whole becomes one body, whose center of gravity is now at or near d. Let the pin c be fixed in the center of the whirling-board, and the deep groove b cut in the flat side of the demi-globe be put upon the pin, fo as the pin may be in the center of  $A \mid See \mid Fig.$ 5. where this groove is represented at b and let Fig. 5. the whirling-board be turned by the winch, which will carry the little ball B (Fig. 4.) with its wire C, and the demi-globe A, all round the center-pin c i; and then, the centrifugal force of the little ball B, which weighs only one ounce, will be fo great, as to draw off the demi-globe A, which weighs two pounds, until the end of the groove at e strikes against the pin c, and so prevents the demi-globe A from going any farther: otherwise, the centrifugal force of B would have been great enough to have carried A quite off the whirling-board. Which shews, that if the fun were placed in the very center of the orbits of the planets, it could not possibly remain there; for the centrifugal forces of the planets would carry them quite off, and the fun D 2

with them; especially when several of them hap. pened to be in any one quarter of the heavens. For the fun and planets are as much connected by the mutual attraction that subsists between them, as the bodies A and B are by the wire C which is fixed into them both. And even if there were but one fingle planet in the whole heavens to go round ever fo large a fun in the center of its orbit, its centrifugal force would foon carry off both itself and the fun. For, the greatest body placed in any part of free space might be easily moved: because if there were no other body to attract it, it could have no weight or gravity of itself; and consequently, though it could have no tendency of itself to remove from that part of space, yet it might be very easily

moved by any other substance.

10. As the centrifugal force of the light body B will not allow the heavy body A to remain in the center of motion, even though it be 24 times as heavy as B; let us now take the ball A (Fig. 6.) which weighs 6 ounces, and connect it by the wire C with the ball B, which weighs only one ounce; and let the fork E be fixed into the center of the whirling-board: then hang the balls upon the fork by the wire C in fuch a manner, that they may exactly balance each other; which will be when the center of gravity between them, in the wire at d, is supported by the fork. And this center of gravity is as much nearer to the center of the ball A, than to the center of the ball B, as A is heavier than B, allowing for the weight of the wire on each fide of the fork. This done, let the machine be put into motion by the winch; and the balls A and B will go round their common center of gravity d, keeping their balance, because either will not allow

Fig. 6.

the other to fly off with it. For, supposing the ball B to be only one ounce in weight, and the ball A to be fix ounces; then, if the wire C were equally heavy on each fide of the fork, the center of gravity d would be fix times as far from the center of the ball B as from that of the ball A, and confequently B will revolve with a velocity fix times as great as A does; which will give B fix times as much centrifugal force as any fingle ounce of A has: but then, as B is only one ounce, and A fix ounces, the whole centrifugal force of A will exactly balance the whole centrifugal force of B: and therefore, each body will detain the other fo as to make it keep in its This shews that the fun and planets must all move round the common center of gravity of the whole system, in order to preserve that just balance which takes place among them. For, the planets being as unactive and dead as the above balls, they could no more have put themfelves into motion than these balls can; nor have kept in their orbits without being balanced at first with the greatest degree of exactness upon their common center of gravity, by the Almighty hand that made them and put them in motion.

Perhaps it may be here asked, that since the center of gravity between these balls must be supported by the fork E in this experiment, what prop it is that supports the center of gravity of the solar system, and consequently bears the weight of all the bodies in it; and by what is the prop itself supported? The answer is easy and plain; for the center of gravity of our balls must be supported, because they gravitate toward the earth, and would therefore fall to it: but as the sun and planets gravitate only toward

D 3

one another, they have nothing else to fall to; and therefore have no occasion for any thing to support their common center of gravity: and if they did not move round that center, and consequently acquire a tendency to sly off from it by their motions, their mutual attractions would soon bring them together; and so the whole would become one mass in the sun: which would also be the case if their velocities round the sun were not quick enough to create a centrifugal

force equal to the fun's attraction.

But after all this nice adjustment, it appears evident that the Deity cannot withdraw his regulating hand from his works, and leave them to be folely governed by the laws which he has imprest upon them at first. For if he should once leave them fo, their order would in time come to an end; because the planets must neceffarily diffurb one another's motions by their mutual attractions, when several of them are in the fame quarter of the heavens; as is often the case: and then, as they attract the fun more toward that quarter than when they are in a manner dispersed equably around him, if he was not at that time made to describe a portion of a larger circle round the common center of gravity, the balance would then be immediately destroyed; and as it could never restore itself again, the whole system would begin to fall together, and would in time unite in a mass at the sun. Of this diffurbance we have a very remarkable instance in the comet which appeared lately; and which, in going last up before from the sun, went fo near to Jupiter, and was fo affected by his attraction, as to have the figure of its orbit much changed; and not only fo, but to have its period altered,

altered, and its course to be different in the heavens from what it was last before.

11. Take away the fork and balls from the Fig. 7. whirling-board, and place the trough AB thereon, fixing its center to the center of the whirling-board by the pin H. In this trough are two balls D and E, of unequal weights, connected by a wire f; and made to flide easily upon the wire C stretched from end to end of the trough, and made fast by nut-screws on the outside of the ends. Let these balls be so placed upon the wire C, that their common center of gravity g may be directly over the center of the whirling-board. Then, turn the machine by the winch, ever fo fwiftly, and the trough and balls will go round their center of gravity, fo as neither of the balls will fly off; because, on account of the equilibrium, each ball detains the other with an equal force acting against it. But if the ball E be drawn a little more toward the end of the trough at A, it will remove the center of gravity toward that end from the center of motion; and then, upon turning the machine, the little ball E will fly off, and strike with a considerable force against the end A, and draw the great ball B into the middle of the trough. Or, if the great ball D be drawn toward the end B of the trough, so that the center of gravity may be a little toward that end from the center of motion, and the machine be turned by the winch, the great ball D will fly off, and strike violently against the end B of the trough, and will bring the little ball E into the middle of it. If the trough be not made very frong, the ball D will break through it.

12. The reason why the tides rise at the same Of the absolute time on opposite sides of the earth, and tides.

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confequently in opposite directions, is made abundantly plain by a new experiment on the whirling table. The cause of their rising on the side next the moon every one understands to be owing to the moon's attraction: but why they should rise on the opposite side at the same time, where there is no moon to attract them, is perhaps not fo generally understood. For it would feem that the moon should rather draw the waters (as it were) closer to that side, than raise them upon it, directly contrary to her attractive force. Let the circle abcd represent the earth, with its side c turned toward the moon, which will then attract the waters so, as to raise them from c to g. But the question is, why should they rise as high at that very time on the opposite side, from a to In order to explain this, let there be a plate AB fixed upon one end of the flat bar DC; with fuch a circle drawn upon it as abcd (in Fig. 8.) to represent the round figure of the earth and fea; and fuch an ellipsis as efgh to represent the fwelling of the tide at e and g, occasioned by the influence of the moon. Over this plate AB let the three ivory balls e, f, g, be hung by the filk lines b, i, k, fastened to the tops of the crooked wires H, I, K, in such a manner, that the ball at e may hang freely over the fide of the circle e, which is farthest from the moon M at the other end of the bar; the ball at f may hang freely over the center, and the ball at g hang over the fide of the circle g, which is nearest the moon. The ball f may represent the center of the earth, the ball g fome water on the fide next the moon, and the ball e some water on the opposite side. On the back of the moon M is fixt the short bar N parallel to the horizon, and there are three holes in it above the little weights p, q, r. A

Fig. 8.

Fig. 9.

filk thread o is tied to the line k close above the ball g, and passing by one side of the moon M, goes through a hole in the bar N, and has the weight p hung to it. Such another thread n is tied to the line i, close above the ball f, and passing through the center of the moon M and middle of the bar N, has the weight q hung to it, which is lighter than the weight p. A third thread m is tied to the line b, close above the ball e, and passing by the other side of the moon M, through the bar N, has the weight r hung to it,

which is lighter than the weight q.

The use of these three unequal weights is to represent the moon's unequal attraction at different distances from her. With whatever force the attracts the center of the earth, the attracts the fide next her with a greater degree of force, and the fide farthest from her with a less. So, if the weights are left at liberty, they will draw all the three balls toward the moon with different degrees of force, and cause them to make the appearance shewn in Fig. 10; by which means Fig. 10. they are evidently farther from each other than they would be if they hung at liberty by the lines b, i, k; because the lines would then hang perpendicularly. This shews, that as the moon attracts the fide of the earth which is nearest her with a greater degree of force than she does the center of the earth, she will draw the water on that fide more than she draws the center, and so cause it to rise on that side: and as she draws the center more than she draws the opposite side, the center will recede farther from the furface of the water on that opposite side, and so leave it as high there as she raised it on the side next to her. for, as the center will be in the middle between the

the tops of the opposite elevations, they must of course be equally high on both sides at the same time.

But upon this supposition the earth and moon would foon come together: and to be fure they would, if they had not a motion round their common center of gravity, to create a degree of centrifugal force fufficient to balance their mu-This motion they have; for as tual attraction. the moon goes round her orbit every month, at the distance of 240000 miles from the earth's center, and of 234000 miles from the center of gravity of the earth and moon, fo does the earth go round the fame center of gravity every month at the distance of 6000 miles from it; that is, from it to the center of the earth. Now as the earth is (in round numbers) 8000 miles in diameter, it is plain that its fide next the moon is only 2000 miles from the common center of gravity of the earth and moon; its center 6000 miles distant therefrom; and its farther side from Therefore the centrifugal the moon 10000. forces of these parts are as 2000, 6000, and 10000; that is, the centrifugal force of any fide of the earth, when it is turned from the moon, is five times as great as when it is turned toward the moon. And as the moon's attraction (exprest by the numbers 6000) at the earth's center keeps the earth from flying out of this monthly circle, it must be greater than the centrifugal force of the waters on the fide next her; and consequently, her greater degree of attraction on that fide is sufficient to raise them; but as her attraction on the opposite side is less than the centrifugal force of the water there, the excels of this force is sufficient to raise the water just as high

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high on the opposite side .- To prove this expe- Fig. 9. rimentally, let the bar DC with its furniture be fixed upon the whirling-board of the machine (Fig. 1.) by pushing the pin P into the center of the board; which pin is in the center of gravity of the whole bar with its three balls e, f, g, and moon M. Now if the whirling-board and bar be turned flowly round by the winch, until the ball f hangs over the center of the circle, as in Fig. 11. the ball g will be kept toward the moon by the heaviest weight p (Fig. 9.) and the ball e, on account of its greater centrifugal force, and the leffer weight r, will fly off as far to the other side, as in Fig. 11. And thus, while the machine is kept turning, the balls e and g will hang over the end of the ellipsis l f k. that the centrifugal force of the ball e will exceed the moon's attraction just as much as her attraction exceeds the centrifugal force of the ball g, while her attraction just balances the centrifugal force of the ball f, and makes it keep in its circle. And hence it is evident, that the tides must rise to equal heights at the same time on opposite sides of the earth. This experiment, to the best of my knowledge, is entirely new.

From the principles thus established, it is The evident that the earth moves round the sun, and earth's not the sun round the earth; for the centrisugal motion law will never allow a great body to move round strated. a small one in any orbit whatever; especially when we find that if a small body moves round a great one, the great one must also move round the common center of gravity between them two. And it is well known that the quantity of matter in the sun is 227000 times as great as the quantity of matter in the sarth. Now, as the sun's distance

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distance from the earth is at least 81,000,000 of miles, if we divide that distance by 227,000, we shall have only 357 for the number of miles that the center of gravity between the fun and earth is distant from the sun's center. And as the fun's femidiameter is 4 of a degree, which, at fo great a distance as that of the sun, must be no less than 381500 miles, if this be divided by 357, the quotient will be nearly 1069, which shews that the common center of gravity between the fun and earth is within the body of the fun; and is only the 1069 part of his femidiameter

from his center toward his furface.

All globular bodies, whose parts can yield, and which do not turn on their axes, must be perfect spheres, because all parts of their surfaces are equally attracted toward their centers. But all fuch globes which do turn on their axes will be oblate spheroids; that is, their surfaces will be higher, or farther from the center, in the equatorial than in the polar regions. For, as the equatorial parts move quickeft, they must have the greatest centrifugal force; and will therefore recede farthest from the axis of motion. Thus, if two circular hoops AB and CD, made thin and flexible, and croffing one another at right angles, be turned round their axis EF by means of the winch m, the wheel n, and pinion o, and the axis be loofe in the pole or intersection e, the middle parts A, B, C, D, will swell out so as to strike against the sides of the frame at F and G, if the pole e, in finking to the pin E, be not stopt by it from finking farther: fo that the whole will appear of an oval figure, the equatorial diameter being considerably longer than the polar. That our earth is of this figure, is demonstrable from actual meafurement

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Fig. 12.

furement of fome degrees on its furface, which are found to be longer in the frigid zones than in the torrid: and the difference is found to be fuch as proves the earth's equatorial diameter to be 36 miles longer than its axis.—Seeing then, the earth is higher at the equator than at the poles, the fea, which like all other fluids naturally runs downward (or toward the places which are nearest the earth's center) would run toward the polar regions, and leave the equatorial parts dry, if the centrifugal force of the water, which carried it to those parts, and so raised them, did not detain and keep it from running back again toward the poles of the earth.

## LECT. III.

## Of the mechanical Powers.

IF we confider bodies in motion, and com- The foun-I pare them together, we may do this either dation of with respect to the quantities of matter they all mechacontain, or the velocities with which they are moved. The heavier any body is, the greater is the power required either to move it or to stop its motion: and again, the fwifter it moves, the greater is its force. So that the whole momentum or quantity of force of a moving body is the refult of its quantity of matter multiplied by the velocity with which it is moved, And when the products arising from the multiplication of the particular quantities of matter in any two bodies by their respective velocities are equal, the momenta or entire forces are so too. Thus, fuppose a body, which we shall call A, to weigh 40 pounds, and to move at the rate of two miles

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in a minute; and another body, which we shall call B, to weigh only four pounds, and to move 20 miles in a minute; the entire forces with which these two bodies would strike against any obstacle would be equal to each other, and therefore it would require equal powers to stop them. For 40 multiplied by 2 gives 80, the force of the body A: and 20 multiplied by 4 gives 80,

the force of the body B.

Upon this easy principle depends the whole of mechanics: and it holds univerfally true, that when two bodies are suspended on any machine, fo as to act contrary to each other; if the machine be put into motion, and the perpendicular afcent of one body multiplied into its weight, be equal to the perpendicular descent of the other body multiplied into its weight, those bodies, how unequal soever in their weights, will balance one another in all fituations: for, as the whole afcent of one is performed in the fame time with the whole descent of the other, their respective velocities must be directly as the fpaces they move through; and the excess of weight in one body is compensated by the excess of velocity in the other.—Upon this principle it is easy to compute the power of any mechanical the power engine, whether fimple or compound; for it is but only finding how much fwifter the power moves than the weight does (i. e. how much farther in the fame time) and just so much is the power increased by the help of the engine.

In the theory of this science, we suppose all planes perfectly even, all bodies perfectly smooth, levers to have no weight, cords to be extremely pliable, machines to have no friction; and in short, all impersections must be set aside until

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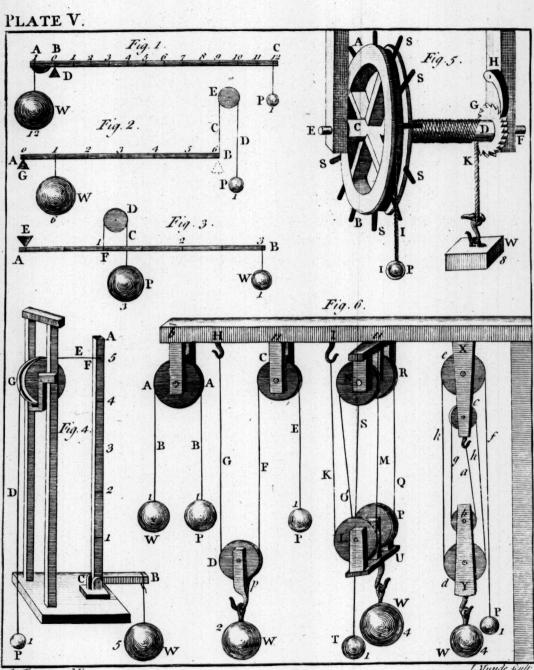
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the theory be established; and then, proper allowances are to be made.

The simple machines, usually called mechanical The mepowers, are six in number, viz. the lever, the chanic
wheel and axle, the pulley, the inclined plane, the
wedge, and the screw.—They are called mechanical powers, because they help us mechanically
to raise weights, move heavy bodies, and overcome resistances, which we could not effect without them.

of which being supported by a prop, all the other parts turn upon that prop as their center of motion: and the velocity of every part or point is directly as its distance from the prop. Therefore, when the weight to be raised at one end is to the power applied to the other to raise it, as the distance of the power from the prop is to the distance of the weight from the prop, the power and weight will exactly balance or counterpoise each other: and as a common lever has next to no friction on its prop, a very little additional power will be sufficient to raise the weight.

There are four kinds of levers. 1. The common fort, where the prop is placed between the weight and the power; but much nearer to the weight than to the power. 2. When the prop is at one end of the lever, the power at the other, and the weight between them. 3. When the prop is at one end, the weight at the other, and the power applied between them. 4. The bended lever, which differs only in form from the first fort, but not in property. Those of the first and second kind are often used in mechanical engines; but there are few instances in which

the third fort is used.

The ba-

A common balance is by fome reckoned a lever of the first kind; but as both its ends are at equal distances from its center of motion, they move with equal velocities; and therefore, as it gives no mechanical advantage, it cannot properly be reckoned among the mechanical powers.

Plate V. Fig. 1. The first kind of lever. A lever of the first kind is represented by the bar ABC, supported by the prop D. Its principal use is to loosen large stones in the ground, or raise great weights to small heights, in order to have ropes put under them for raising them higher by other machines. The parts AB and BC, on different sides of the prop D, are called the arms of the lever: the end A of the shorter arm AB being applied to the weight intended to be raised, or to the resistance to be overcome; and the power applied to the end C of the longer arm BC.

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In making experiments with this machine, the shorter arm AB must be as much thicker than the longer arm BC, as will be fufficient to balance it on the prop. This supposed, let P reprefent a power, whose gravity is equal to I ounce, and W a weight, whose gravity is equal to 12 ounces. Then, if the power be 12 times as far from the prop as the weight is, they will exactly counterpoife; and a fmall addition to the power P will cause it to descend, and raise the weight W; and the velocity with which the power descends will be to the velocity with which the weight rifes, as 12 to 1: that is, directly as their distances from the prop; and confequently, as the spaces through which they Hence, it is plain, that a man, who by his natural strength, without the help of any machine, could support a hundred weight, will by the help of this lever be enabled to support twelve

twelve hundred. If the weight be lefs, or the power greater, the prop may be placed fo much farther from the weight, and then it can be raised to a proportionably greater height. For, univerfally, if the intensity of the weight multiplied into its distance from the prop be equal to the intensity of the power multiplied into its distance from the prop, the power and weight will exactly balance each other; and a little addition to the power will raise the weight. in the present instance, the weight W is 12 ounces, and its distance from the prop is I inch; and 12 multiplied by 1 is 12; the power P is equal to I ounce, and its distance from the prop is 12 inches, which multiplied by I is 12 again; and therefore there is an equilibrium between them. So, if a power equal to 2 ounces be applied at the distance of 6 inches from the prop, it will just balance the weight W; for 6 multiplied by 2 is 12, as before. And a power equal to 3 ounces placed at 4 inches distance from the prop would be the fame; for 3 times 4 is 12; and fo on, in proportion.

The statera or Roman steelyard is a lever of The steel-this kind, and is used for finding the weights of sard. different bodies by one single weight placed at different distances from the prop or center of motion D. For, if a scale hangs at A, the extremity of the shorter arm AB, is of such a weight as will exactly counterpose the longer arm BC; if this arm be divided into as many equal parts as it will contain, each equal to AB, the single weight P (which we may suppose to be I pound) will serve for weighing any thing as heavy as itself, or as many times heavier as there are divisions in the arm BC, or any quantity between its own weight and that quantity.

As for example, if P be I pound, and placed at the first division 1 in the arm BC, it will balance I pound in the scale at A: if it be removed to the fecond division at 2, it will balance 2 pounds in the scale: if to the third, 3 pounds; and so on to the end of the arm BC. If each of these integral divisions be subdivided into as many equal parts, as a pound contains ounces, and the weight P be placed at any of thefe fubdivisions, so as to counterpoise what is in the scale, the pounds and odd ounces therein will by that means be afcertained.

To this kind of lever may be reduced feveral forts of instruments, fuch as scissars, pincers, inuffers; which are made of two levers acting contrary to one another: their prop or center of motion being the pin which keeps them toge-

ther.

In common practice, the longer arm of this lever greatly exceeds the weight of the shorter: which gains great advantage, because it adds to

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The feof lever.

A lever of the fecond kind has the weight cond kind between the prop and the power. In this, as well as the former, the advantage gained is as the distance of the power from the prop to the distance of the weight from the prop: for the respective velocities of the power and weight are in that proportion; and they will balance each other when the intensity of the power multiplied by its distance from the prop is equal to the intensity of the weight multiplied by its diftance from the prop. Thus, if AB be a lever on which the weight W of 6 ounces hangs at the distance of 1 inch from the prop G, and a power P equal to the weight of 1 ounce hangs at the end B, 6 inches from the prop, by the cord CD

Fig. 2.

CD going over the fixed pulley E, the power will just support the weight: and a small addition to the power will raise the weight, I inch for every 6 inches that the power descends.

This lever shews the reason why two men carrying a burden upon a flick between them, bear unequal shares of the burden in the inverse proportion of their distances from it. For it is well known, that the nearer any of them is to the burden, the greater share he bears of it: and if he goes directly under it, he bears the whole. So, if one man be at G, and the other at P, having the pole or stick AB resting on their shoulders; if the burden or weight W be placed five times as near the man at G, as it is to the man at P, the former will bear five times as much weight as the latter. This is likewife applicable to the case of two horses of unequal strength to be so yoked, as that each horse may draw a part proportionate to his ftrength; which is done by fo dividing the beam they pull, that the point of traction may be as much nearer to the stronger horse than to the weaker, as the strength of the former exceeds that of the latter.

To this kind of lever may be reduced oars, rudders of ships, doors turning upon hinges, cutting-knives which are fixed at the point of the blade, and the like.

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If in this lever we suppose the power and The third weight to change places, so that the power may kind of be between the weight and the prop, it will become a lever of the third kind: in which, that there may be a balance between the power and the weight, the intenfity of the power must exceed the intensity of the weight, just as much as the distance of the weight from the prop ex-E 2 ceeds

Fig. 3.

ceeds the distances of the power from it. Thus, let E be the prop of the lever AB, and W a weight of 1 pound, placed 3 times as far from the prop, as the power P acts at F, by the cord C going over the fixed pulley D; in this case, the power must be equal to three pounds, in order to support the weight.

To this fort of lever are generally referred the bones of a man's arm: for when we lift a weight by the hand, the muscle that exerts its force to raise that weight, is fixed to the bone about one tenth part as far below the elbow as the hand is. And the elbow being the center round which the lower part of the arm turns, the muscle must therefore exert a force ten times

as great as the weight that is raifed.

As this kind of lever is a disadvantage to the moving power, it is never used but in cases of necessity; such as that of a ladder, which being fixed at one end, is by the strength of a man's arms reared against a wall. And in clock-work, where all the wheels may be reckoned levers of this kind, because the power that moves every wheel, except the first, acts upon it near the center of motion by means of a small pinion, and the resistance it has to overcome, acts against the teeth round its circumference.

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The fourth kind of lever. Fig. 4.

The fourth kind of lever differs nothing from the first, but in being bended for the sake of convenience. ACB is a lever of this fort, bended at C, which is its prop, or center of motion. P is a power acting upon the longer arm AC at F, by means of the cord DE going over the pulley G; and W is a weight or resistance acting upon the end B of the shorter arm BC. If the power is to the weight, as CB is to CF, they are in equilibrio. Thus, suppose W to be  $\S$  pounds

pounds acting at the diffance of one foot from the center of motion C, and P to be 1 pound acting at F, five feet from the center C, the power and weight will just balance each other. A hammer when used in drawing a nail is a lever of this fort.

2. The fecond mechanical power is the wheel The wheel and axle, in which the power is applied to the and axle. circumference of the wheel, and the weight is raifed by a rope which coils about the axle as the wheel is turned round. Here it is plain that the velocity of the power must be to the velocity of the weight, as the circumference of the wheel is to the circumference of the axle: and confequently, the power and weight will balance each other, when the intensity of the power is to the intensity of the weight, as the circumference of the axle is to the circumference of the wheel. Let AB be a wheel, CD its axle, and suppose Fig. 5. the circumference of the wheel to be 8 times as great as the circumference of the axle; then, a power P equal to 1 pound hanging by the cord I, which goes round the wheel, will balance a weight W of 8 pounds hanging by the rope K, which goes round the axle. And as the friction on the pivots or gudgeons of the axle is but small, a small addition to the power will cause it to descend, and raise the weight: but the weight will rife with only an eighth part of the velocity wherewith the power descends, and confequently, through no more than an eighth part of an equal space, in the same time. If the wheel be pulled round by the handles S, S, the power will be increased in proportion to their length. And by this means, any weight may be raifed as high as the operator pleafes.

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To this fort of engine belong all cranes for raising great weights; and in this case, the wheel may have cogs all round it instead of handles, and a fmall lantern or trundle may be made to work in the cogs, and be turned by a winch; which will make the power of the engine to exceed the power of the man who works it, as much as the number of revolutions of the winch exceed those of the axle D, when multiplied by the excess of the length of the winch above the length of the femidiameter of the axle, added to the femidiameter or half thickness of the rope K, by which the weight is drawn up. Thus, fuppose the diameter of the rope and axle taken together, to be 13 inches, and confequently, half their diameters to be  $6\frac{1}{2}$  inches; fo that the weight W will hang at 61 inches perpendicular diffance from below the center of the axle. Now, let us suppose the wheel AB, which is fixt on the axle, to have 80 cogs, and to be turned by means of a winch  $6\frac{1}{2}$  inches long, fixt on the axis of a trundle of 8 staves or rounds, working in the cogs of the wheel .-Here it is plain, that the winch and trundle would make 10 revolutions for one of the wheel AB, and its axis D, on which the rope K winds in raising the weight W; and the winch being no longer than the fum of the femidiameters of the great axle and rope, the trundle could have no more power on the wheel, than a man could have by pulling it round by the edge, because the winch would have no greater velocity than the edge of the wheel has, which we here suppose to be ten times as great as the velocity of the rifing weight: fo that, in this case, the power gained would be as 10 to 1. But if the length of the winch be 13 inches, the power gained

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gained will be as 20 to 1: if 191 inches (which is long enough for any man to work by) the power gained would be as 30 to 1; that is, a man could raise 30 times as much by such an engine, as he could do by his natural strength without it, because the velocity of the handle of the winch would be 30 times as great as the velocity of the rifing weight; the absolute force of any engine being in proportion of the velocity of the power to the velocity of the weight raifed by it.—But then, just as much power or advantage as is gained by the engine, fo much time is loft in working it. In this fort of machines it is requisite to have a ratchet-wheel G on one end of the axle, with a catch H to fall into its teeth; which will at any time support the weight, and keep it from descending, if the person who turns the handle should, through inadvertency or careleffness, quit his hold while the weight is raising. And by this means, the danger is prevented which might otherwise happen by the running down of the weight when left at liberty.

3. The third mechanical power or engine con- The pulfifts either of one moveable pulley, or a fystem of leypulleys; fome in a block or case which is fixed,
and others in a block which is moveable, and
rises with the weight. For though a single
pulley that only turns on its axis, and moves not
out of its place, may serve to change the direction of the power, yet it can give no mechanical advantage thereto; but is only as the beam
of a balance, whose arms are of equal length and
weight. Thus, if the equal weights W and P Fig. 6,
hang by the cord BB upon the pulley A, whose
frame b is fixed to the beam HI, they will counterpoise each other, just in the same manner as
if the cord were cut in the middle, and its two

E 4

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ends hung upon the hooks fixt in the pulley at A and A, equally diffant from its center.

But if a weight W hangs at the lower end of the moveable block p of the pulley D, and the cord GF goes under that pulley, it is plain that the half G of the cord bears one half of the weight W, and the half F the other; for they Therefore, bear the whole between them. whatever holds the upper end of either rope, fustains one half of the weight: and if the cord at F be drawn up to as to raise the pulley D to C, the cord will then be extended to its whole length, all but that part which goes under the pulley; and confequently the power that draws the cord will have moved twice as far as the pulley D with its weight W rifes; on which account, a power whose intensity is equal to one half of the weight will be able to support it, because if the power moves (by means of a small addition) its velocity will be double the velocity of the weight; as may be feen by putting the cord over the fixt pulley C (which only changes the direction of the power, without giving any advantage to it) and hanging on the weight P, which is equal only to one half the weight W; in which case there will be an equilibrium, and a little addition to P will cause it to descend, and raise W through a space equal to one half of that through which P descends.—Hence, the advantage gained will be always equal to twice the number of pulleys in the moveable or undermost block. So that, when the upper or fixt block u contains two pulleys, which only turn on their axis, and the lower or moveable block U contains two pulleys, which not only turn upon their axis, but also rise with the block and weight; the advantage gained by this is as 4 to the working



working power. Thus, if one end of the rope KMOQ be fixed to a hook at I, and the rope passes over the pulleys N and R, and under the pulleys L and P, and has a weight T, of one pound, hung to its other end at T, this weight will balance and support a weight W of four pounds hanging by a hook at the moveable block U, allowing the said block as a part of the weight. And if as much more power be added, as is sufficient to overcome the friction of the pulleys, the power will descend with four times as much velocity as the weight rises, and consequently through four times as much space.

The two pulleys in the fixed block X, and the two in the moveable block Y, are in the fame case with those last mentioned; and those in the lower block give the same advantage to

the power.

As a fystem of pulleys has no great weight, and lies in a small compass, it is easily carried about; and can be applied, in a great many cases, for raising weights, where other engines cannot. But they have a great deal of friction on three accounts: 1. Because the diameters of their axes bear a very considerable proportion to their own diameters; 2. Because in working they are apt to rub against one another, or against the sides of the block; 3. Because of the stiffness of the rope that goes over and under them.

4. The fourth mechanical power is the in- The indined plane, and the advantage gained by it is clined as great as its length exceeds its perpendicular plane. height. Let AB be a plane parallel to the hori- Plate VI. 2011, and CD a plane inclined to it; and suppose Fig. 1. the whole length CD to be three times as great as the perpendicular height GfF: in this case, the cylinder E will be supported upon the plane CD.

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CD, and kept from rolling down upon it, by a power equal to a third part of the weight of the cylinder. Therefore, a weight may be rolled up this inclined plane with a third part of the power which would be fufficient to draw it up by the fide of an upright wall. If the plane was four times as long as high, a fourth part of the power would be fufficient; and fo on, in pro-Or, if a weight was to be raifed from a floor to the height GF, by means of the machine ABCD, (which would then act as a half wedge, where the refistance gives way only on one fide) the machine and weight would be in equilibrio when the power applied at GF was to the weight to be raised, as GF to GB; and if the power be increased, so as to overcome the friction of the machine against the floor and weight, the machine will be driven, and the weight raised: and when the machine has moved its whole length upon the floor, the weight will be raifed to the whole height from G to F.

upon an inclined plane, is to the force of its absolute gravity, by which it would descend perpendicularly in a free space, as the height of the plane is to its length. For, suppose the plane AB to be parallel to the horizon, the cylinder Cwill keep at rest upon any part of the plane If the plane be fo elevated, where it is laid. that its perpendicular height D is equal to half its length AB, the cylinder will roll down upon the plane with a force equal to half its weight; for it would require a power (acting in the direction of AB) equal to half its weight, to keep it from rolling. If the plane AB be elevated, fo as to be perpendicular to the horizon, the cylinder C will descend with its whole force of

The force wherewith a rolling body descends

Fig. 3.

Fig. 2.

Fig. 4.

gravity, because the plane contributes nothing to its support or hindrance; and therefore, it would require a power equal to its whole weight

to keep it from descending.

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Let the cylinder C be made to turn upon Fig. 5. flender pivots in the frame D, in which there is a hook e, with a line G tied to it: let this line go over the fixed pulley H, and have its other end tied to the hook in the weight I. If the weight of the body I, be to the weight of the cylinder C, added to that of its frame D, as the perpendicular height of the plane L M is to its length AB, the weight will just support the cylinder upon the plane, and a fmall touch of a finger will either cause it to ascend or descend with equal ease: then, if a little addition be made to the weight I, it will descend, and draw the cylinder up the plane. In the time that the cylinder moves from A to B, it will rife through the whole height of the plane ML; and the weight will defeen from H to K, through a space equal to the whole length of the plane A B.

If the machine be made to move upon rollers or friction-wheels, and the cylinder be supported upon the plane CB by a line G parallel to the plane, a power fomewhat less than that which drew the cylinder up the plane will draw the plane under the cylinder, provided the pivots of the axes of the friction-wheels be small, and the wheels themselves be pretty large. For, let the machine ABC (equal in length and height to Fig. 6. ABM, Fig. 5.) move upon four wheels, two whereof appear at D and E; and the third under C, while the fourth is hid from fight by the horizontal board a. Let the cylinder F be laid upon the lower end of the inclined plane CB, and the line G be extended from the frame of the cylinder, about fix feet parallel to the plane

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plane CB; and, in that direction, fixed to a hook in the wall; which will support the cylinder, and keep it from rolling off the plane. Let one end of the line H be tied to a hook at C in the machine, and the other end to a weight K, fomewhat less than that which drew the cylinder up the plane before. If this line be put over the fixed pulley I, the weight K will draw the machine along the horizontal plane L, and under the cylinder F: and when the machine has been drawn a little more than the whole length CA, the cylinder will be raifed to d, equal to the perpendicular height AB above the horizontal part The reason why the machine must be drawn further than the whole length CA is, because the weight F rises perpendicular to CB.

To the inclined plane may be reduced all hatchets, chifels, and other edge-tools which are

chamfered only on one fide.

5. The fifth mechanical power or machine is the wedge, which may be confidered as two equally inclined planes DEF and CEF, joined together at their bases eEFO: then DC is the whole thickness of the wedge at its back ABCD, where the power is applied: EF is the depth or heighth of the wedge: DF the length of one of its sides, equal to CF the length of the other side; and OF is its sharp edge, which is entered into the wood intended to be split by the force of a hammer or mallet striking perpendicularly on its back. Thus ABb is a wedge driven into the cleft CDE of the wood FG.

Fig. 9.

The

wedge,

Fig. 8.

When the wood does not cleave at any diftance before the wedge, there will be an equilibrium between the power impelling the wedge downward, and the refistance of the wood acting against the two sides of the wedge when the power is to the resistance, as half the thickness of the wedge at its back is to the length of either of its fides; because the resistance then acts perpendicular to the sides of the wedge. But, when the resistance on each side acts parallel to the back, the power that balances the resistances on both sides will be as the length of the whole back of the wedge is to double its perpendicula.

height.

When the wood cleaves at any distance before the wedge (as it generally does) the power impelling the wedge will not be to the resistance of the wood, as the length of the back of the wedge is to the length of both its sides; but as half the length of the back is to the length of either side of the cleft, estimated from the top or acting part of the wedge. For, if we suppose the wedge to be lengthened down from b to the bottom of the cleft at E, the same proportion will hold; namely, that the power will be to the resistance, as half the length of the back of the wedge is to the length of either of its sides: or, which amounts to the same thing, as the whole length of the back is to the length of both the sides.

In order to prove what is here advanced concerning the wedge, let us suppose the wedge to be divided lengthwise into two equal parts; and then it will become two equal inclined planes; one of which, as abc, may be made use of as a Fig. 7. half wedge for feparating the moulding cd from the wainfcot AB. It is evident, that when this half wedge has been driven its whole length ac between the wainfcot and moulding, its fide a c will be at ed; and the moulding will be feparated to f g from the wainfcot. Now, from what has been already proved of the inclined plane, it appears, that to have an equilibrium between the power impelling the half wedge, and the refiftance of the moulding, the former must be to the latter,

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latter, as ab to ac; that is, as the thickness of the back which receives the stroke is to the length of the fide against which the moulding acts. Therefore, fince the power upon the half wedge is to the relistance against its fide, as the half back ab is to the whole fide ac, it is plain, that the power upon which the whole wedge (where the whole back is double the half back) must be to the relifance against both its fides, as the thickness of the whole back is to the length of both the fides; supposing the wedge at the bottom of the cleft: or as the thickness of the whole back to the length of both fides of the cleft, when the wood splits at any distance before the wedge. For, when the wedge is driven quite into the wood, and the wood splits at ever so fmall a distance before its edge, the top of the wedge then becomes the acting part, because the wood does not touch it any where elfe. And fince the bottom of the cleft must be considered as that part where the whole stickage or resistance is accumulated, it is plain, from the nature of the lever, that the farther the power acts from the refistance, the greater is the advantage.

Some writers have advanced, that the power of the wedge is to the refistance to be overcome, as the thickness of the back of the wedge is to the length only of one of its sides; which seems very strange: for, if we suppose AB to be a strong instexible bar of wood or iron fixt into the ground at CB, and D and E to be two blocks of marble lying on the ground on opposite sides of the bar; it is evident that the block D may be separated from the bar to the distance d, equal to ab, by driving the inclined plane or half wedge abo down between them; and the block E may be separated to an equal distance on the other side, in like manner, by the half wedge cda.

Fig. 10-

But the power impelling each half wedge will be to the resistance of the block against its side, as the thickness of that half wedge is to its perpendicular height, because the block will be driven off perpendicularly to the side of the bar AB. Therefore the power to drive both the half wedges is to both the resistances, as both the half backs is to the perpendicular height of each half wedge. And if the bar be taken away, the blocks put close together, and the two half wedges joined to make one; it will require as much force to drive it down between the blocks, as is equal to the sum of the separate powers acting upon the half wedges when the bar was between them.

To confirm this by an experiment, let two Fig. 11. cylinders, as AB and CD, be drawn toward one another by lines running over fixed pulleys, and a weight of 40 ounces hanging at the lines belonging to each cylinder: and let a wedge of 40 ounces weight, having its back just as thick as either of its sides is long, be put between the cylinders, which will then act against each side with a resistance equal to 40 ounces, while its own weight endeavours to bring it down and separate them. And here, the power of the wedge's gravity impelling it downward, will be to the relistance of both the cylinders against the wedge, as the thickness of the wedge is to double its perpendicular height; for there will then be an equilibrium between the weight of the wedge and the refistance of the cylinders against it, and it will remain at any height between them; requiring just as much power to push it upward as to pull it downward.—If another wedge of equal weight and depth with this, and only half as thick, be put between the cylinders, it will require twice as much weight to be hung at the

ends

ends of the lines which draw them together, to keep the wedge from going down between them. That is, a wedge of 40 ounces, whose back is only equal to half its perpendicular height, will require 80 ounces to each cylinder, to keep it in an equilibrium between them: and twice 80 is 160, equal to four times 40. So that the power will be always to the resistance, as the thickness of the back of the wedge is to twice its perpendicular height, when the cylinders move off in a line at right angles to that perpendicular.

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Fig. 11.

The best way, though perhaps not the neatest, that I know of, for making a wedge with its appurtenances for fuch experiments, is as follows. Let KILM and LMNO be two flat pieces of wood, each about fifteen inches long, and three or four in breadth, joined together by a hinge at LM; and let P be a graduated arch of brass, on which the said pieces of wood may be opened to any angle not more than 60 degrees, and then fixt at the given angle by means of the two screws a and b. Then, IKNO will represent the back of the wedge, LM its sharp edge which enters the wood, and the outfides of the pieces KILM and LMNO the two fides of the wedge against which the wood acts in cleaving. By means of the faid arch, the wedge may be opened fo, as to adjust the thickness of its back in any proportion to the length of either of its fides, but not to exceed that length: and any weight as p may be hung to the wedge upon the hook M, which weight, together with the weight of the wedge itself, may be considered as the impelling power; which is all the fame in the experiment, whether it be laid upon the back of the wedge to push it down, or hung to its edge to pull it down. Let AB and CD be two wooden cylinders, each about two inches thick, where they

they touch the outsides of the wedge; and let their ends be made like two round flat plates, to keep the wedge from flipping off edgewife from between them. Let a small cord with a loop on one end of it, go over a pivot in the end of each cylinder, and the cords S and T belonging to the cylinder AB go over the fixt pulleys W and X, and be fastened at their other ends to the bar wx, on which any weight as Z may be hung at pleafure. In like manner, let the cords  $\mathcal{Q}$  and R belonging to the cylinder CD go over the fixt pulleys V and U to the bar vu, on which a weight Y equal to Z may be hung. These weights, by drawing the cylinders toward one another, may be confidered as the refistance of the wood acting equally against opposite sides of the wedge; the cylinders themselves being suspended near, and parallel to each other, by their pivots in loops on the lines E, F, G, H; which lines may be fixed to hooks in the cieling of the room. The longer these lines are, the better; and they should never be less than four feet each. The farther also the pulleys V, U and X, W are from the cylinders, the truer will the experiments be: and they may turn upon pins fixed into the wall.

In this machine, the weights  $\Upsilon$  and Z, and the weight p, may be varied at pleasure, so as to be adjusted in proportion of double the wedge's perpendicular height to the thickness of its back: and when they are so adjusted, the wedge will be in equilibrio with the resistance of the cylinders.

The wedge is a very great mechanical power, fince not only wood but even rocks can be split by it; which would be impossible to effect by the lever, wheel and axle, or pulley: for the force of the blow, or stroke, shakes the cohering parts, and thereby makes them separate more easily.

F. 6. The

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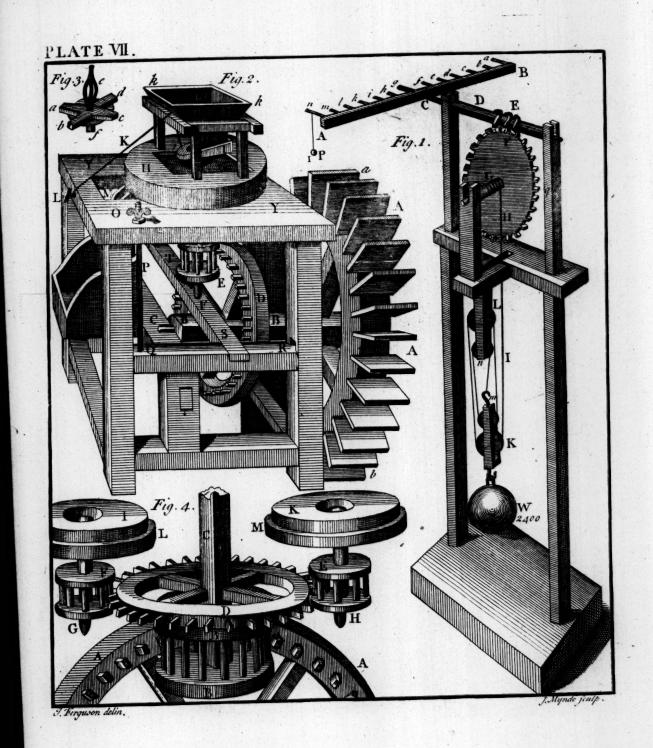
Fig. 12,

13.

6. The fixth and last mechanical power is the fcrew; which cannot properly be called a fimple machine, because it is never used without the application of a lever or winch to affift in turning it: and then it becomes a compound engine of a very great force either in pressing the parts of bodies closer together, or in raising great weights. It may be conceived to be made by cutting a piece of paper ABC (Fig. 12.) into the form of an inclined plane or half wedge, and then wrapping it round a cylinder AB (Fig. 13). And here it is evident, that the winch E must turn the cylinder once round before the weight of refistance D can be moved from one spiral winding to another, as from d to c: therefore, as much as the circumference of a circle, described by the handle of the winch, is greater than the interval or diffance between the spirals, so Thus, supposing much is the force of the screw. the distance between the spirals to be half an inch, and the length of the winch to be twelve inches; the circle described by the handle of the winch where the power acts will be 76 inches nearly, or about 152 half inches, and confequently 152 times as great as the diffance between the spirals: and therefore a power at the handle, whose intensity is equal to no more than a fingle pound, will balance 152 pounds acting against the screw; and as much additional force, as is fufficient to overcome the friction, will raise the 152 pounds; and the velocity of the power will be to the velocity of the weight, as 152 to 1. Hence it appears, that the longer the winch is, and the nearer the fpirals are to one another, so much the greater is

A machine for shewing the force or power of the screw may be contrived in the following manner:





manner: Let the wheel C have a screw ab on Fig. 14. its axle, working in the teeth of the wheel D, which suppose to be 48 in number. It is plain, that for every time the wheel C and screw ab are turned round by the winch A, the wheel D will be moved one tooth by the screw; and therefore, in 48 revolutions of the winch, the wheel D will be turned once round. Then, if the circumference of a circle described by the handle of the winch A be equal to the circumference of a proove e round the wheel D, the velocity of the handle will be 48 times as great as the velocity of any given point in the groove. Consequently, if a line G (above number 48) goes round the groove e, and has a weight of 48 pounds hung to it below the pedestal EF, a power equal to one pound at the handle will balance and support the weight.—To prove this by experiment, let the circumferences of the grooves of the wheels Cand D be equal to one another; and then if a weight H of one pound be suspended by a line going round the groove of the wheel C, it will balance a weight of 48 pounds hanging by the line G; and a finall addition to the weight Hwill cause it to descend, and so raise up the other weight.

If the line G, instead of going round the groove e of the wheel D, goes round its axle I; the power of the machine will be as much inteased, as the circumference of the groove e exceeds the circumference of the axle: which, supposing it to be six times, then one pound at H will balance e times e, or 288 pounds hung to the line on the axle: and hence the power or advantage of this machine will be as 288 to e. That is to say, a man, who by his natural strength could lift a hundred weight, will be

F 2

able

able to raise 288 hundred, or 143 ton weight

by this engine.

But the following engine is still more powerful, on account of its having the addition of four pulleys: and in it we may look upon all the mechanical powers as combined together, Plate VII. even if we take in the balance. For, as the axle

Fig. 1.

chanical powers.

D of the bar AB enters its middle at C, it is plain that if equal weights are suspended upon any two A combi- pins equi-diftant from the axis C, they will counnation of terpoife each other.—It becomes a lever by all the me-hanging a small weight P upon the pin n, and a weight as much heavier upon either of the pins b, c, d, e, or f, as is in proportion to the pins being fo much nearer the axis. The wheel and axle FG is evident; so is the screw E which takes in the inclined plane, and with it the half wedge. Part of a cord goes round the axle, the rest under the lower pulleys K, m, over the upper pulleys L, n, and then it is tied to a hook at min the lower or moveable block, on which the weight W hangs.

> In this machine, if the wheel F has 30 teeth, it will be turned once round in thirty revolutions of the bar AB, which is fixt on the axis D of the screw E: if the length of the bar is equal to twice the diameter of the wheel, the pins a and n at the ends of the bar will move 60 times as fast as the teeth of the wheel do: and confequently, one ounce at P will balance 60 ounces hung upon a tooth at q in the horizontal diameter of the wheel. Then, if the diameter of the wheel F is ten times as great as the diameter of the axle G, the wheel will have 10 times the velocity of the axle; and therefore one ounce P at the end of the lever AC will balance 10 times 60 or 600 ounces hung to the rope H which goes round

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round the axle. Lastly, if four pulleys be added, they will make the velocity of the lower block K, and weight W, four times less than the velocity of the axle: and this being the last power in the machine, which is four times as great as that gained by the axle, it makes the whole power of the machine 4 times 600, or 2400. So that a man who could lift one hundred weight in his arms by his natural strength, would be able to raise 2400 times as much by this engine.—But it is here as in all other mechanical cases; for the time lost is always as much as the power gained, because the velocity with which the power moves will ever exceed the velocity with which the weight rifes, as much as the intensity of the weight exceeds the intensity of the power.

The friction of the screw itself is very considerable; and there are sew compound engines, but what, upon account of the friction of the parts against one another, will require a third part more of power to work them when loaded, than what is sufficient to constitute a balance between the weight and the power.

## LECT. IV.

Of mills, cranes, wheel-carriages, and the engine for driving piles.

A S these engines are so universally useful, it would be needless to make any apology for describing them.

In a common breast-mill, where the fall of Plate VII.

water may be about ten feet, AA is the great Fig. 2.

wheel, which is generally about 17 or 18 feet in A common

F 3 diameter.

mill.

diameter, reckoned from the outermost edge of any float board at a to that of its opposite float at b. To this wheel the water is conveyed through a channel, and by falling upon the wheel, turns it round.

On the axis BB of this wheel, and within the mill-house, is a wheel D, about 8 or 9 feet diameter, having 61 cogs, which turn a trundle E containing ten upright staves or rounds; and when these are the number of cogs and rounds, the trundle will make  $6\frac{1}{10}$  revolutions for one

revolution of the wheel.

The trundle is fixt upon a strong iron axis called the spindle, the lower end of which turns in a brass foot, fixt at F, in the horizontal beam ST called the bridge-tree; and the upper part of the spindle turns in a wooden bush fixt into the nether millstone which lies upon beams in the floor TT. The top part of the spindle above the bush is square, and goes into a square hole in a strong iron cross abcd (see Fig. 3.) called the rynd; under which, and close to the bush, is a round piece of thick leather upon the spindle, which it turns round at the same time as it does the rynd.

The rynd is let into grooves in the under furface of the running millstone G (Fig. 2.) and so turns it round in the same time that the trundle E is turned round by the cog-wheel D. This millstone has a large hole quite through its middle, called the eye of the stone, through which the middle part of the rynd and upper end of the spindle may be seen; while the sour ends of the rynd lie hid below the stone in their grooves.

The end T of the bridge-tree TS (which supports the upper millstone G upon the spindle) is fixed into a hole in the wall; and the end S is let into a beam  $\mathcal{Q}R$  called the brayer, whose end R

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remains fixt in a mortife: and its other end 9 hangs by a strong iron rod P which goes through the floor YY, and has a screw-nut on its top at 0; by the turning of which nut, the end Q of the brayer is raifed or depressed at pleasure; and confequently the bridge-tree TS and upper mill-By this means, the upper millstone may be fet as close to the under one, or raised as high from it, as the miller pleases. The nearer the millstones are to one another, the finer they grind the corn, and the more remote from one

another, the coarfer.

The upper millstone G is inclosed in a round box H, which does not touch it any where; and is about an inch diftant from its edge all around. On the top of this box flands a frame for holding the hopper kk, to which is hung the shoe I by two lines fastened to the hind-part of it, fixed upon hooks in the hopper, and by one end of the crook-string K fastened to the fore-part of it at i; the other end being twisted round the pin L. As the pin is turned one way, the string draws up the shoe closer to the hopper, and so lessens the aperture between them; and as the pin is turned the other way, it lets down the shoe, and enlarges the aperture.

If the shoe be drawn up quite to the hopper, no corn can fall from the hopper into the mill; if it be let a little down, some will fall: and the quantity will be more or less, according as the thoe is more or less let down. For the hopper is open at bottom, and there is a hole in the bottom of the shoe, not directly under the bottom of the hopper, but forwarder toward the end i, over

the middle of the eye of the millstone.

There is a square hole in the top of the spindle, Fig. 3. in which is put the feeder e: this feeder (as the ipindle

fpindle turns round) jogs the shoe three times in each revolution, and so causes the corn to run constantly down from the hopper through the shoe, into the eye of the millstone, where it falls upon the top of the rynd, and is, by the motion of the rynd, and the leather under it, thrown below the upper stone, and ground between it and the lower one. The violent motion of the stone creates a centrifugal force in the corn going round with it, by which means it gets farther and farther from the center, as in a spiral, in every revolution, until it be thrown quite out; and, being then ground, it falls through a spout M, called the mill-eye, into the trough N.

When the mill is fed too fast, the corn bears up the stone, and is ground too coarse; and besides, it clogs the mill so as to make it go too slow. When the mill is too slowly fed, it goes too fast, and the stones by their attrition are apt to strike fire against one another. Both which inconveniences are avoided by turning the pin L backward or forward, which draws up or lets down the shoe; and so regulates the feeding as

the miller fees convenient.

The heavier the running millstone is, and the greater the quantity of water that falls upon the wheel, so much the faster will the mill bear to be fed; and consequently so much the more it will grind. And on the contrary, the lighter the stone, and the less the quantity of water, so much flower must the feeding be. But when the stone is considerably wore, and become light, the mill must be fed slowly at any rate; otherwise the stone will be too much borne up by the corn under it, which will make the meal coarse.

The quantity of power required to turn a heavy millstone is but very little more than what

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is fufficient to turn a light one: for as it is fupported upon the spindle by the bridge-tree ST, and the end of the spindle that turns in the brass foot therein being but small, the odds arising from the weight is but very inconsiderable in its action against the power or force of the water. And besides, a heavy stone has the same advantage as a heavy sty; namely, that it regulates the motion much better than a light one.

In order to cut and grind the corn, both the upper and under millstones have channels or furrows cut into them, proceeding obliquely from the center toward the circumference. And thefe furrows are cut perpendicularly on one fide and obliquely on the other into the stone, which gives each furrow a sharp edge, and in the two ftones they come, as it were, against one another like the edges of a pair of scissars: and so cut the corn, to make it grind the easier when it falls upon the places between the furrows. These are cut the same way in both stones when they lie upon their backs, which makes them run cross ways to each other when the upper stone is inverted by turning its furrowed furface toward that of the lower. For, if the furrows of both stones lay the same way, a great deal of the corn would be driven onward in the lower furrows. and so come out from between the stones without being either cut or bruifed.

When the furrows become blunt and shallow by wearing, the running stone must be taken up, and both stones new drest with a chisel and hammer. And every time the stone is taken up, there must be some tallow put round the spindle upon the bush, which will soon be melted by the heat the spindle acquires from its turning and rubbing against the bush, and so will get in

between

between them: otherwise the bush would take

fire in a very little time.

The bush must embrace the spindle quite close, to prevent any shake in the motion, which would make some parts of the stones grate and fire against each other; while other parts of them would be too far asunder, and by that means

fpoil the meal in grinding.

Whenever the spindle wears the bush so as to begin to shake in it, the stone must be taken up, and a chifel drove into feveral parts of the bush; and when it is taken out, wooden wedges must be driven into the holes; by which means the bush will be made to embrace the spindle close all around it again. In doing this, great care must be taken to drive equal wedges into the bush on opposite sides of the spindle; otherwise it will be thrown out of the perpendicular, and so hinder the upper stone from being set parallel to the under one, which is absolutely necessary for making good work. When any accident of this kind happens, the perpendicular polition of the spindle must be restored by adjusting the bridge-tree ST by proper wedges put between it and the brayer QR.

It often happens, that the rynd is a little wrenched in laying down the upper stone upon it; or is made to sink a little lower upon one side of the spindle than on the other; and this will cause one edge of the upper stone to drag all around upon the other, while the opposite edge will not touch. But this is easily set to rights, by raising the stone a little with a lever, and putting bits of paper, cards, or thin chips,

between the rynd and the stone.

The diameter of the upper stone is generally about six feet, the lower stone about an inch

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more: and the upper stone, when new, contains about 22½ cubic feet, which weighs somewhat more than 19000 pounds. A stone of this diameter ought never to go more than 60 times round in a minute; for if it turns faster, it will heat the meal.

The grinding furface of the under stone is a little convex from the edge to the center, and that of the upper stone a little more concave: so that they are farthest from one another in the middle, and come gradually nearer toward the edges. By this means, the corn at its first entrance between the stones is only bruised; but as it goes farther on toward the circumference or edge, it is cut smaller and smaller; but at last sinely ground just before it comes out from between them.

The water-wheel must not be too large, for if it be, its motion will be too slow; nor too little, for then it will want power. And for a mill to be in perfection, the floats of the wheel ought to move with a third part of the velocity of the water, and the stone to turn round once in a second of time.

In order to conftruct a mill in this perfect manner, observe the following rules:

1. Measure the perpendicular height of the sall of water, in feet, above that part of the wheel on which the water begins to act; and call that, the height of the sall

the height of the fall.

2. Multiply this conftant number 64.2882 by the height of the fall in feet, and the square root of the product shall be the velocity of the water at the bottom of the fall, or the number of feet that the water there moves per second.

3. Divide the velocity of the water by 3, and the quotient shall be the velocity of the float-boards of the wheel; or the number of feet they

must

must each go through in a second, when the water acts upon them fo, as to have the greatest

power to turn the mill.

4. Divide the circumference of the wheel in feet by the velocity of its floats in feet per fecond, and the quotient shall be the number of feconds in which the wheel turns round.

5. By this last number of seconds divide 60: and the quotient shall be the number of turns of

the wheel in a minute.

6. Divide 60 (the number of revolutions the millstone ought to have in a minute) by the number of turns of the wheel in a minute, and the quotient shall be the number of turns the millstone ought to have for one turn of the wheel.

7. Then, as the number of turns of the wheel in a minute is to the number of turns of the millstone in a minute, so must the number of staves in the trundle be to the number of cogs in the wheel, in the nearest whole numbers that can be found.

By these rules I have calculated the following table to a water-wheel 18 feet diameter, which I apprehend may be a good fize in general.

To construct a mill by this table, find the height of the fall of water in the first column, and against that height, in the fixth column, you have the number of cogs in the wheel, and staves in the trundle, for causing the millstone to make about 60 revolutions in a minute, as near as possible, when the wheel goes with a third part of the velocity of the water. And it appears by the 7th column, that the number of cogs in the wheel, and staves in the trundle, are so near the truth for the required purpose, that the least number of revolutions of the millstone in a minute is between 59 and 60, and the greatest number never amounts to 61.

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## The MILL-WRIGHT's TABLE.

Height of the fall of water.	Velo- city of the water per fe- cond.	Velo- city of the wheel per fe- cond.		Revolutions of the mill-flone for one of the wheel.	Cogs in the wheel and flaves in the trundle.	Rev. of the mill- flone per min. by these flaves and cogs.
Feet.	of a foot.	of a foot.	of a Rev.	of a Rev.	Staves. Cogs.	of a Rev.
I 2	8.02	2.67	2.83	21.20		59.92 60.00
3	13.89			12.22	98 8	60.14
4	16.04		5.67	10.58	95 9	59.87
5 6	17.93	5.98	6.34	9.46	85 9	59.84
	19.64		6.94	8.64	78 9	60.10
7 8	21.21		7.50	8.00		60.00
	22.68		8.02	7 . 48		59.67
9 10	24.05			7.05	70 IO 67 IO	59.57
1	25.35 26.59		8.97 9.40	6.38	The second secon	60.09
	27.77	9.26	9.82	6.11		59.90
	28.91	9.64	10.22	5.87		60.18
1	30.00		10.60	5.66		59.36
	31.05	10.35	10.99	5.46		60.48
1	32.07	10.69		5.29	53 10	60.10
	33.06		11.70	5.13		59.67
		11.34		4.99	-	60.10
		11.65		4.85		60.61
20	35.80	11.95	12.08	4.73	47 10	59.59
I	2	3	4	5	6	7

Such

Such a mill as this, with a fall of water about 71 feet, will require about 32 hogsheads every minute to turn the wheel with a third part of the velocity with which the water falls; and to overcome the refistance arising from the friction of the geers and attrition of the stones in grinding the corn.

The greater fall the water has, the less quantity of it will ferve to turn the mill. The water is kept up in the mill-dam, and let out by a fluice called the penflock, when the mill is to go. When the penftock is drawn up by means of a lever, it opens a paffage through which the water flows to the wheel: and when the mill is to be ftopt, the penftock is let down, which stops the

water from falling upon the wheel.

A less quantity of water will turn an overshotmill (where the wheel has buckets instead of float-boards) than a breaft-mill, where the fall of the water feldom exceeds half the height Ab of the wheel. So that, where there is but a small quantity of water, and a fall great enough for the wheel to lie under it, the bucket (or overshot) wheel is always used. But where there is a large body of water, with a little fall, the breast or floatboard wheel must take place. Where the water runs only upon a little declivity, it can act but flowly upon the under part of the wheel at b; in which case, the motion of the wheel will be very flow: and therefore, the floats ought to be very long, though not high, that a large body of water may act upon them; fo that what is wanting in velocity may be made up in power; and then the cog-wheel may have a greater number of cogs in proportion to the rounds in the trundle, in order to give the millstone a sufficient degree of velocity.

They who have read what is faid in the first lecture, concerning the acceleration of bodies

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falling freely by the power of gravity acting constantly and uniformly upon them, may perhaps ask, Why should the motion of the wheel be equable, and not accelerated, feeing the water acts constantly and uniformly upon it? The plain answer is, That the velocity of the wheel can never be fo great as the velocity of the water that turns it; for, if it should become so great, the power of the water would be quite lost upon the wheel, and then there would be no proper force to overcome the friction of the geers and attrition of the stones. Therefore, the velocity with which the wheel begins to move, will increase no longer than till its momentum or force is balanced by the refiftance of the working parts of the mill; and then the wheel will go on with an equable motion.

[If the cog-wheel D be made about 18 inches A hand-diameter, with 30 cogs, the trundle as small in mill. proportion, with 10 staves, and the millstones be each about two feet in diameter, and the whole work be put into a strong frame of wood, as represented in the figure, the engine will be a hand-mill for grinding corn or malt in private samilies. And then, it may be turned by a winch instead of the wheel AA: the millstone making three revolutions for every one of the winch. If a heavy fly be put upon the axle B, near the winch, it will help to regulate the motion.]

If the cogs of the wheel and rounds of the trundle could be put in as exactly as the teeth are cut in the wheels and pinions of a clock, then the trundle might divide the wheel exactly: that is to fay, the trundle might make a given number of revolutions for one of the wheel, without a fraction. But as any exact number is not necessary in mill-work, and the cogs and rounds cannot be fet in fo truly as to make all

the intervals between them equal; a skilful mill-wright will always give the wheel what he calls a bunting cog; that is, one more than what will answer to an exact division of the wheel by the trundle. And then, as every cog comes to the trundle, it will take the next staff or round behind the one which it took in the former revolution: and by that means will wear all the parts of the cogs and rounds which work upon one another equally, and to equal distances from one another in a little time; and so make a true uniform motion throughout the whole work. Thus, in the above water-mill, the trundle has 10 staves, and the wheel 61 cogs.

Fig. 4.

Sometimes, where there is a fufficient quantity of water, the cog-wheel AA turns a large trundle BB, on whose axis C is fixed the horizontal wheel D, with cogs all around its edge, turning two trundles E and F at the same time; whose axes or spindles G and H turn two millstones I and K, upon the fixed stones L and M. And when there is not work for them both, either may be made to lie quiet, by taking out one of the staves of its trundle, and turning the vacant place toward the cog-wheel D. And there may be a wheel fixt on the upper end of the great upright axle C for turning a couple of boulting-mills; and other work for drawing up the facks, fanning and cleaning the corn, fharpening of tools, &c.

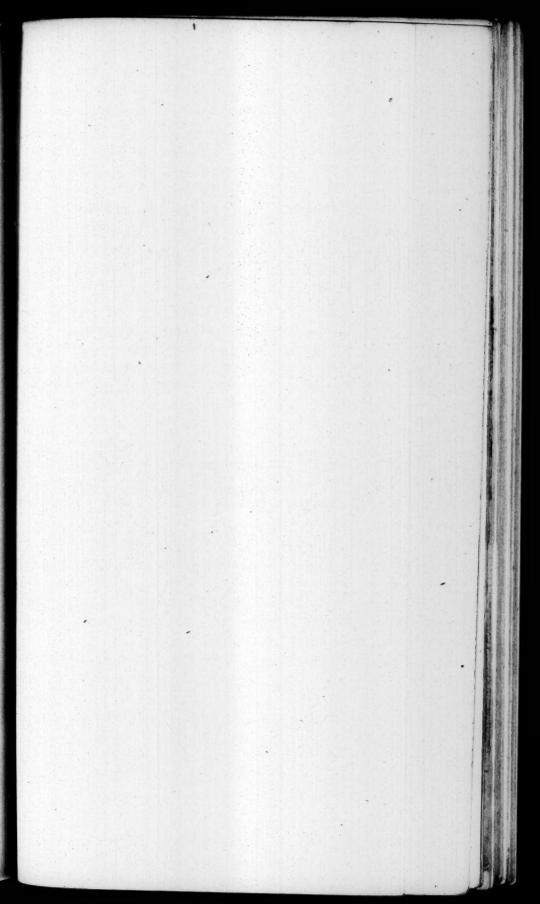
A horse-

If, instead of the cog-wheel AA and trundle BB, horizontal levers be fixed into the axle C, below the wheel D; then, horses may be put to these levers for turning the mill: which is often done where water cannot be had for that purpose

pose.

A wind-

The working parts of a wind-mill differ very little from those of a water-mill; only the former



J. Mynde fc.

J. Ferguson delin.

is turned by the action of the wind upon four fails, every one of which ought (as is generally believed) to make an angle of 54½ degrees with a plane perpendicular to the axis on which the arms are fixt for carrying them. It being demonstrable, that when the fails are fet to such an angle, and the axis turned endwise toward the wind, the wind has the greatest power upon the fails. But this angle answers only to the case of a vane or fail just beginning to move\*: for, when the vane has a certain degree of motion, it yields to the wind: and then that angle must be increased to give the wind its full effect.

Again, the increase of this angle should be different, according to the different velocities from the axis to the extremity of the vane. At the axis it should be  $54\frac{2}{3}$  degrees, and thence continually decrease, giving the vane a twist, and so causing all the ribs of the vane to lie in dif-

ferent planes.

Lastly, These ribs ought to decrease in length from the axis to the extremity, giving the vane a curvilineal form; so that no part of the force of any one rib be spent upon the rest, but all move on independent of each other. All this is required to give the sails of a wind-mill their true form: and we see both the twist and the diminution of the ribs exemplified in the wings of birds.

It is almost incredible to think with what velocity the tips of the sails move when acted upon by a moderate gale of wind. I have several times counted the number of revolutions made by the sails in ten or sisteen minutes; and from the length of the arms from tip to tip, have computed, that if a hoop of that diameter was to run upon the ground with the same velo-

See MACLAURIN's Fluxions, near the end.

city that it would move if put upon the fail-arms, it would go upward of 30 miles in a hour.

As the ends of the fails nearest the axis cannot move with the fame velocity that the tips or farthest ends do, although the wind acts equally strong upon them; perhaps a better position than that of stretching them along the arms directly from the center of motion, might be to have them fet perpendicularly across the farther ends of the arms, and there adjusted lengthwise to the proper angle. For, in that case, both ends of the fails would move with the fame velocity; and being farther from the center of motion, they would have fo much the more power: and then, there would be no occasion for having them so large as they are generally made; which would render them lighter, and confequently, there would be fo much the less friction on the thick neck of the axle where it turns in the wall.

A crane.

Plate VIII. Fig. 1.

A crane is an engine by which great weights are raised to certain heights, or let down to certain depths. It consists of wheels, axles, pulleys, ropes, and a gib or gibbet. rope H is hooked to the weight K, a man turns the winch A, on the axis whereof is the trundle B, which turns the wheel C, on whose axis D is the trundle E, which turns the wheel F with its upright axis G, on which the great rope HHwinds as the wheel turns; and going over a pulley I at the end of the arm d of the gib c c de, it draws up the heavy weight K; which, being raifed to a proper height, as from a ship to the quay, is then brought over the quay by pulling the wheel Z round by the handles z, z, which turns the gib by means of the half wheel b fixt on the gib-post cc, and the strong pinion a fixt on the axis of the wheel Z. This wheel gives the man that turns it an absolute command over

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the gib, so as to prevent it from taking any unlucky swing, such as often happens when it is only guided by a rope tied to its arm d; and people are frequently hurt, sometimes killed, by such accidents.

The great rope goes between two upright rollers i and k, which turn upon gudgeons in the fixed beams f and g; and as the gib is turned toward either fide, the rope bends upon the roller next that fide. Were it not for these rollers, the gib would be quite unmanageable; for the moment it were turned ever fo little toward any fide, the weight K would begin to descend, because the rope would be shortened between the pulley I and axis G; and fo the gib would be pulled violently to that fide, and either be broke to pieces, or break every thing that came in its way. These rollers must be placed fo, that the fides of them, round which the rope bends, may keep the middle of the bended part directly even with the center of the hole in which the upper gudgeon of the gib turns in the beam The truer these rollers are placed, the easier the gib is managed, and the lefs apt to fwing either way by the force of the weight K.

A ratchet wheel  $\mathcal{Q}$  is fixt upon the axis D, near the trundle E; and into this wheel the catch or click R falls. This hinders the machinery from running back by the weight of the burthen K, if the man who raises it should happen to be careless, and so leave off working at the winch

A fooner than he ought to do.

When the weight K is raised to its proper height from the ship, and brought over the quay by turning the gib about, it is let down gently upon the quay, or into a cart standing thereon, in the following manner: A man takes hold of the rope tt (which goes over the pulley

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v and is tied to a hook at S in the catch R) and fo disengages the catch from the ratchet-wheel  $\mathcal{Q}$ ; and then, the man at the winch A turns it backward, and lets down the weight K. But if the weight pulls too hard against this man, another lays hold of the stick V, and by pulling it downward, draws the gripe U close to the wheel Y, which, by rubbing hard against the gripe, hinders the too quick descent of the weight; and not only  $\Omega$ , but even stops it at any time, if required. By this means, heavy goods may be either raised or let down at pleasure, without any danger of hurting the men who work the

engine.

When part of the goods are craned up, and the rope is to be let down for more, the catch R is first disengaged from the ratchet-wheel Q, by pulling the cord t; then the handle q is turned half round backward, which, by the crank nn in the piece o, pulls down the frame b between the guides m and m (in which it flides in a groove) and fo disengages the trundle B from the wheel C: and then, the heavy hook  $\beta$  at the end of the rope H descends by its own weight, and turns back the great wheel F with its trundle E, and the wheel C; and this last wheel acts like a fly against the wheel F and hook  $\beta$ ; and fo hinders it from going down too quick; while the weight X keeps up the gripe U from rubbing against the wheel T, by means of a cord going from the weight, over the pulley w to the hook W in the gripe; fo that the gripe never touches the wheel, unless it be pulled down by the handle V.

When the crane is to be fet at work again, for drawing up another burthen, the handle q is turned half round forward; which, by the crank n n, raifes up the frame h, and causes the

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trundle B to lay hold of the wheel C; and then, by turning the winch A, the burthen of goods K

is drawn up as before.

The crank nn turns pretty stiff in the mortise near o, and stops against the farther end of it when it has got just a little beyond the perpendicular; so that it can never come back of itself: and therefore, the trundle B can never come away from the wheel C, until the handle q be turned half round backward.

The great rope runs upon rollers in the lever LM, which keeps it from bending between the axle at G and the pulley I. This lever turns upon the axis N by means of the weight O, which is just fufficient to keep its end L up to the rope; so that, as the great axle turns, and the rope coils round it, the lever rises with the rope, and prevents the coilings from going over one another.

The power of this crane may be estimated thus: suppose the trundle B to have 13 staves or rounds, and the wheel C to have 78 fpur cogs: the trundle E to have 14 staves, and the wheel F 56 cogs. Then, by multiplying the staves of the trundles, 13 and 14, into one another, their product will be 182; and by multiplying the cogs of the wheels, 78 and 56, into one another, their product will be 4368, and dividing 4368 by 182, the quotient will be 24; which shews that the winch A makes 24 turns for one turn of the wheel F and its axle G on which the great rope or chain HIH So that, if the length or radius of the winch A were only equal to half the diameter of the great axle G, added to half the thickness of the rope H, the power of the crane would be as 24 to 1: but the radius of the winch being double the above length, it doubles the faid power, and fo makes it as 48 to 1: in which case, a man may raise 48 times as much weight

· by

by this engine as he could do by his natural flrength without it, making proper allowance for the friction of the working parts.—Two men may work at once, by having another winch on the opposite end of the axis of the trundle under B; and this will make the power double.

If this power be thought greater than what may be generally wanted, the wheels may be made with fewer cogs in proportion to the staves in the trundles; and so the power may be of whatever degree is judged to be requisite. But if the weight be so great as will require yet more power to raise it, suppose a double quantity, then the rope H may be put under a moveable pulley, as  $\delta$ , and the end of it tied to a hook in the gib at  $\epsilon$ ; which will give a double power to the machine, and so raise a double weight hooked to the block of the moveable pulley.

When only small burthens are to be raised, this may be quickly done by men pushing the axle G round by the long spokes y, y, y, y; having first disengaged the trundle B from the wheel G: and then, this wheel will only act as a sly upon the wheel F; and the catch R will prevent its running back, if the men should inadvertently leave off pushing before the burthen be unhooked

from B.

Lastly, When very heavy burthens are to be raised, which might endanger the breaking of the cogs in the wheel F; their force against these cogs may be much abated by men pushing round the long spokes y, y, y, y, while the man at A turns the winch.

I have only shewn the working parts of this crane, without the whole of the beams which support them; knowing that these are easily supposed,

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supposed, and that if they had been drawn, they would have hid a great deal of the working parts from fight, and also confused the figure.

Another very good crane is made in the fol- Another lowing manner. A A is a great wheel turned crane. by men walking within it at H. On the part Fig. 2. C, of its axle BC, the great rope D is wound as the wheel turns; and this rope draws up goods in the fame way as the rope HH does in the above mentioned crane, the gib-work here being supposed to be of the same fort. But these cranes are very dangerous to the men in the wheel; for, if any of the men should chance to fall, the burthen will make the wheel run back and throw them all about within it: which often breaks their limbs, and fometimes kills them. The late ingenious Mr. Padmore of Briftol (whose contrivance the forementioned crane is, so far as I can remember its construction, after feeing it once about twelve years ago \*) observing this dangerous construction, contrived a method for remedying it, by putting cogs all around the outfide of the wheel, and applying a trundle E to turn it; which increases the power as much as the number of cogs in the wheel is greater than the number of staves in the trundle: and by putting a ratchet-wheel F on the axis of the trundle (as in the abovementioned crane) with a catch to fall into it, the great wheel is stopt from running back by the force of the weight, even if all the men in

<sup>\*</sup> Since the first edition of this book was printed, I have feen the same crane again; and do find, that though the working parts are much the same as above described, yet the method of raising or lowering the trundle B, and the catch R, are better contrived than I had described them.

it should leave off walking. And by one man working at the winch I, or two men at the opposite winches when needful, the men in the wheel are much assisted, and much greater weights are raised, than could be by men only within the wheel. Mr. Padmore put also a gripe-wheel G upon the axis of the trundle, which being pinched in the same manner as described in the former crane, heavy burthens may be let down without the least danger. And before this contrivance, the lowering of goods was always attended with the utmost danger to the men in the wheel; as every one must be sensible of, who has seen such engines at work.

And it is furprifing that the mafters of wharfs and cranes should be so regardless of the limbs, or even lives of their workmen, that excepting the late Sir James Creed of Greenwich, and some gentlemen at Bristol, there is scarce an instance of any who has used this safe contrivance.

Wheelcarriages.

The structure of wheel-carriages is generally so well known, that it would be needless to describe them. And therefore, we shall only point out some inconveniencies attending the common method of placing the wheels, and loading the waggons.

In coaches, and all other four-wheeled carriages, the fore-wheels are made of a lefs fize than the hind ones, both on account of turning fhort, and to avoid cutting the braces; otherwife, the carriage would go much eafier if the fore-wheels were as high as the hind-ones, and the higher the better, because they would fink to less depths in little hollowings in the roads, and be the more easily drawn out of them.

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the direc them. But carriers and coachmen give another reason for making the fore-wheels much lower than the hind-wheels; merely, that when they are so, the hind-wheels help to push on the fore ones: which is too unphilosophical and absurd to deserve a resutation, and yet for their satisfaction we shall shew by experiment that it has no

existence but in their own imaginations.

It is plain that the small wheels must turn as much oftener round than the great ones, as their circumferences are less. And therefore, when the carriage is loaded equally heavy on both axles, the fore-axle must sustain as much more friction, and confequently wear out as much fooner, than the hind-axle, as the forewheels are less than the hind-ones. But the great misfortune is, that all the carriers to a man do obstinately persist, against the clearest reason and demonstration, in putting the heavier part of the load upon the fore-axle of the waggon; which not only makes the friction greatest where it ought to be leaft, but also presses the fore-wheels deeper into the ground than the hind-wheels, notwithstanding the fore-wheels, being less than the hind ones, are with so much the greater difficulty drawn out of a hole or over an obstacle, even supposing the weights on their axles were equal. For the difficulty, with equal weights, will be as the depth of the hole Fig. 3. or height of the obstacle is to the semidiameter Thus, if we suppose the small of the wheel. wheel D of the waggon AB to fall into a hole of the depth EF, which is equal to the femidiameter of the wheel, and the waggon to be drawn horizontally along; it is evident, that the point E of the small wheel will be drawn directly against the top of the hole; and theretore,

fore, all the power of horses and men will not be able to draw it out, unless the ground gives way before it. Whereas, if the hind-wheel G falls into fuch a hole, it finks not near fo deep in proportion to its femidiameter; and therefore, the point G of the large wheel will not be drawn directly, but obliquely, against the top of the hole; and so will be easily got out of it. Add to this, that as a small wheel will often fink to the bottom of a hole, in which a great wheel will go but a very little way, the finall wheels ought in all reason to be loaded with less weight than the great ones; and then the heavier part of the load would be less jolted upward and downward, and the horses tired so much the less, as their draught raised the load to less

heights.

It is true, that when the waggon-road is much up hill, there may be danger in loading the hind part much heavier than the fore-part; for then the weight would overhang the hindaxle, especially if the load be high, and endanger tilting up the fore-wheels from the ground. In this case, the fafest way would be to load it equally heavy on both axles; and then, as much more of the weight would be thrown upon the hind-axle than upon the fore one, as the ground rises from a level below the carriage, But as this feldom happens, and when it does, a small temporary weight laid upon the pole between the horses would overbalance the danger; and this weight might be thrown into the waggon when it comes to level ground; it is strange that an advantage so plain and obvious as would arise from loading the hind-wheels heavieft, should not be laid hold of, by complying with this method.

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To confirm these reasonings by experiment, let a small model of a waggon be made, with its fore-wheels 21 inches in diameter, and its hind-wheels 4½; the whole model weighing about 20 ounces. Let this little carriage be loaded any how with weights, and have a small cord tied to each of its ends, equally high from the ground it rests upon; and let it be drawn along a horizontal board, first by a weight in a scale hung to the cord at the fore-part; the cord going over a pulley at the end of the board to facilitate the draught, and the weight just fufficient to draw it along. Then, turn the carriage, and hang the scale and weight to the hind cord, and it will be found to move along with the fame velocity as at first: which shews, that the power required to draw the carriage is all the fame, whether the great or fmall wheels are foremost; and therefore the great wheels do not help in the least to push on the small wheels in the road.

Hang the scale to the fore-cord, and place the fore-wheels (which are the small ones) in two holes, cut three eight parts of an inch deep into the board; then put a weight of 32 ounces into the carriage, over the fore-axle, and an equal weight over the hind one: this done, put 44 ounces into the scale, which will be just sufficient to draw out the fore-wheels: but if this weight be taken out of the scale, and one of 16 ounces put into its place, if the hind-wheels are placed in the holes, the 16 ounce weight will draw them out; which is little more than a third part of what was necessary to draw out the fore-This shews, that the larger the wheels are, the less power will draw the carriage, especially on rough ground. Put

Put 64 ounces over the axle of the hind-wheels, and 32 over the axle of the fore ones, in the carriage; and place the fore-wheels in the holes: then, put 38 ounces into the scale, which will just draw out the fore-wheels; and when the hind ones come to the hole, they will find but very little resistance, because they fink

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But shift the weights in the carriage, by putting the 32 ounces upon the hind-axle, and the 64 ounces upon the fore one; and place the fore-wheels in the holes: then, if 76 ounces be put into the scale, it will be found no more than sufficient to draw out these wheels; which is double the power required to draw them out, when the lighter part of the load was put upon them: which is a plain demonstration of the abfurdity of putting the heaviest part of the load

in the fore-part of the waggon.

Every one knows what an outcry was made by the generality, if not the whole body, of the carriers, against the broad-wheel act; and how hard it was to perfuade them to comply with it, even though the government allowed them to draw with more horses, and carry greater loads, than usual. Their principal objection was, that as a broad wheel must touch the ground in a great many more points than a narrow wheel, the friction must of course be just so much the greater; and confequently, there must be so many more horses than usual, to draw the waggon. I believe that the majority of people were of the fame opinion, not confidering, that if the whole weight of the waggon and load in it bears upon a great many points, each fuftains a proportionably less degree of weight and friction, than when it bears only upon a few points; so that what

what is wanting in one, is made up in the other; and therefore will be just equal under equal degrees of weight, as may be shewn by the follow-

ing plain and eafy experiment.

Let one end of a piece of packthread be fastened to a brick, and the other end to a common scale for holding weights: then, having laid the brick edgewife on a table, and let the scale hang under the edge of the table, put as much weight into the scale as will just draw the brick along the table. Then taking back the brick to its former place, lay it flat on the table, and leave it to be acted upon by the fame weight in the scale as before, which will draw it along with the fame eafe as when it lay upon its edge. In the former case, the brick may be considered as a narrow wheel on the ground; and in the latter as a broad wheel. And fince the brick is drawn along with equal eafe, whether its broad fide or narrow edge touches the table, it fnews that a broad wheel might be drawn along the ground with the fame eafe as a narrow one (fuppofing them equally heavy) even though they should drag, and not roll, as they go along.

As narrow wheels are always finking into the ground, especially when the heaviest part of the load lies upon them, they must be considered as going constantly up hill, even on level ground. And their sides must sustain a great deal of friction by rubbing against the ruts made by them. But both these inconveniencies are avoided by broad wheels; which, instead of cutting and ploughing up the roads, roll them smooth, and harden them; as experience testisses in places where they have been used, especially either on wettish or sandy ground: though after all it must be conessed, that they will not do in stiff clayey cross

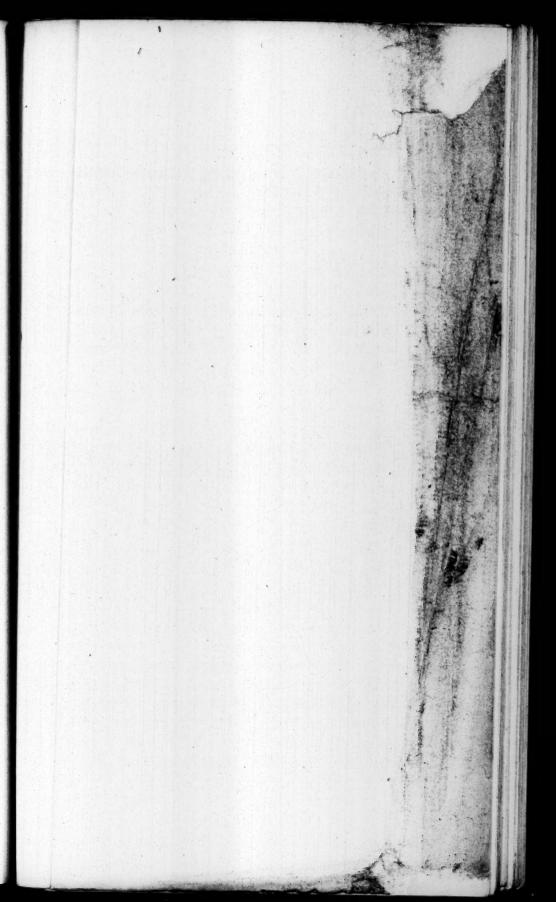
roads; because they would soon gather up as much clay as would be almost equal to the weight

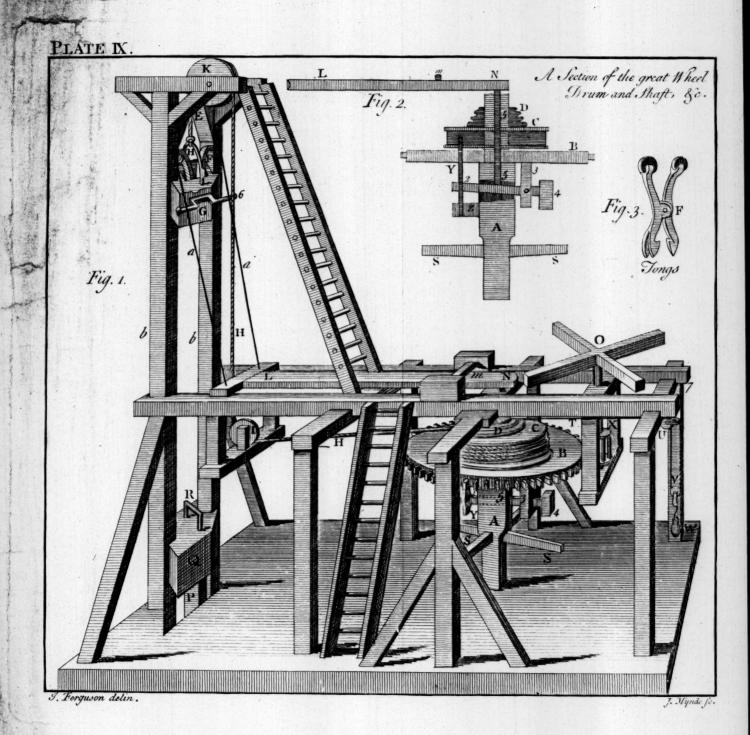
of an ordinary load.

If the wheels were always to go upon fmooth and level ground, the best way would be to make the spokes perpendicular to the naves; that is, to stand at right angles to the axles; because they would then bear the weight of the load perpendicularly, which is the strongest way for But because the ground is generally uneven, one wheel often falls into a cavity or rut when the other does not; and then it bears much more of the weight than the other does: in which case, concave or dishing wheels are best, because when one falls into a rut, and the other keeps upon high ground, the spokes become perpendicular in the rut, and therefore have the greatest strength when the obliquity of the load throws most of its weight upon them; while those on the high ground have less weight to bear, and therefore need not be at their full strength. So that the usual way of making the wheels concave is by much the best.

The axles of the wheels ought to be perfectly straight, that the rim of the wheels may be parallel to each other; for then they will move easiest, because they will be at liberty to go on straight forward. But in the usual way of practice, the axles are bent downward at their ends; which brings the sides of the wheels next the ground nearer to one another than their opposite or higher sides are: and this not only makes the wheels to drag sideways as they go along, and gives the load as much greater power of crushing them than when they are parallel to each other; but also endangers the over-turning of the carriage when any wheel falls into a hole or rut; or

when





when the carriage goes in a road which has one fide lower than the other, as along the fide of a hill. Thus (in the hind view of a waggon or cart) let AE and BF be the great wheels parallel to each other, on their straight axle K, and Fig. 4. HCI the carriage loaded with heavy goods from C to G. Then, as the carriage goes on in the oblique road A a B, the center of gravity of the whole machine and load will be at C\*; and the \* See line of direction CdD falling within the wheel page 13. BF, the carriage will not overfet. But if the wheels be inclined to each other on the ground, Fig. 5. as AE and BF are, and the machine be loaded as before, from C to G, the line of direction CdD falls without the wheel BF, and the whole machine tumbles over. When it is loaded with heavy goods (fuch as lead or iron) which lie low, Fig. 4. it may travel fafely upon an oblique road fo long as the center of gravity is at C, and the line of direction Cd falls within the wheels; but if it be loaded high with lighter goods (fuch as woolpacks) from C to L, the center of gravity is raised Fig. 6. from C to K, which throws the line of direction Kk without the lowest edge of the wheel BF, and then the load overfets the waggon.

If there be some advantage from small forewheels, on account of the carriage turning more easily and short than it can be made to do when they are large; there is at least as great a disadvantage attending them, which is, that as their axle is below the level of the horses breast, the horses not only have the loaded carriage to draw along, but also part of its weight to bear; which tires them sooner, and makes them grow much stiffer in their hams, than they would be if they drew on a level with the foreaxle. And for this reason, we find coach horses

foon

foon become unfit for riding. So that on all accounts it is plain, that the fore-wheels of all carriages ought to be so high, as to have their axles even with the breast of the horses; which would not only give the horses a fair draught, but likewise keep them longer sit for drawing the carriage

riage.

Plate IX. We shall conclude this lecture with a descrip-Fig. 1, 2. tion of Mr. Vauloue's curious engine, which was made use of for driving the piles of Westminsterbridge: and the reader may cast his eyes upon the first and second sigures of the plate, in which the same letters of reference are annexed to the same parts, in order to explain those in the second, which are either partly or wholly hid in the

The pile-

A is the great upright shaft or axle, on which are the great wheel B and drum C, turned by horses joined to the bars S, S. The wheel B turns the trundle X, on the top of whose axis is the fly O, which ferves to regulate the motion, and also to act against the horses, and keep them from falling when the heavy ram Q is discharged to drive the pile P down into the mud in the bottom of the river. The drum C is loofe upon the shaft A, but is locked to the wheel B by the bolt  $\Upsilon$ . On this drum the great rope HH is wound; one end of the rope being fixed to the drum, and the other to the follower G, to which it is conveyed over the pulleys I and K. follower G is contained the tongs F (fee Fig. 3.) that takes hold of the ram Q by the staple Rfor drawing it up. D is a spiral or fusy fixt to the drum, on which is wound the small rope T that goes over the pulley U, under the pulley V, and is fastened to the top of the frame at 7. the pulley block V is hung the counterpoise W, which

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which hinders the follower from accelerating as it goes down to take hold of the ram: for, as the follower tends to acquire velocity in its defcent, the line T winds downward upon the fufy, on a larger and larger radius, by which means the counterpoise W acts stronger and ftronger against it; and so allows it to come down with only a moderate and uniform velocity. The bolt Y locks the drum to the great wheel, being pushed upward by the small lever 2, which goes through a mortife in the shaft A, turns upon a pin in the bar 3 fixt to the great wheel B, and has a weight 4, which always tends to push up the bolt T through the wheel into the drum. L is the great lever turning on the axis m, and refting upon the forcing bar 5, 5, which goes down through a hollow in the shaft A, and

bears up the little lever 2.

By the horses going round, the great rope H is wound about the drum C, and the ram  $\mathcal{D}$  is

is wound about the drum C, and the ram Q is drawn up by the tongs F in the follower G, until the tongs comes between the inclined planes E; which, by shutting the tongs at the top, opens it at the foot, and discharges the ram, which falls down between the guides b b upon the pile P, and drives it by a few strokes as far into the mud as it can go; after which, the top part is fawed off close to the mud, by an engine for that purpose. Immediately after the ram is discharged the piece 6 upon the follower G takes hold of the ropes a, a, which raise the end of the lever L, and cause its end N to descend and press down the forcing bar 5 upon the little lever 2, which by pulling down the bolt  $\Upsilon$ , unlocks the drum Cfrom the great wheel B; and then, the follower, being at liberty, comes down by its own weight to the ram; and the lower ends of the tongs flip

H

over the staple R, and the weight of their heads causes them to fall outward, and shuts upon it. Then the weight 4 pushes up the bolt  $\Upsilon$  into the drum, which locks it to the great wheel, and so

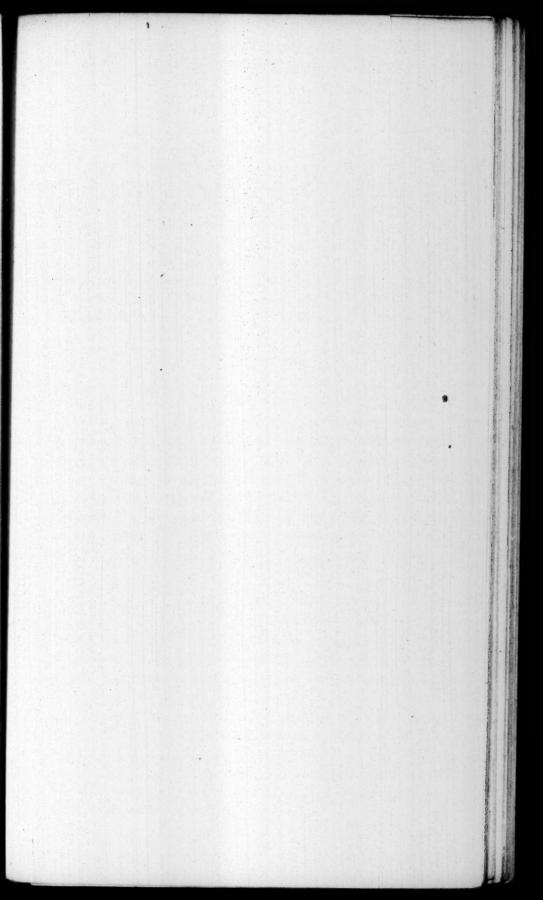
the ram is drawn up as before.

As the follower comes down, it causes the drum to turn backward, and unwinds the rope from it, while the horses, great wheel, trundle, and fly, go on with an uninterrupted motion: and as the drum is turning backward, the counterposite W is drawn up, and its rope  $\mathcal{T}$  wound upon the spiral fusy D.

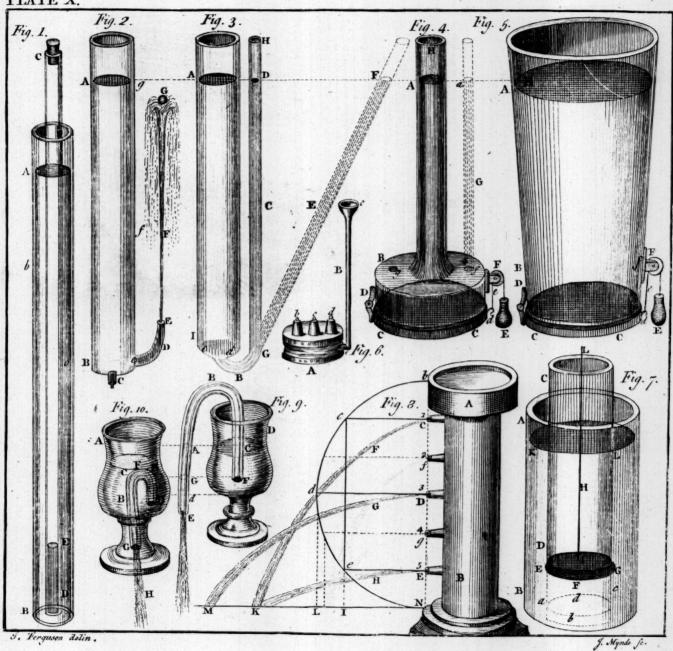
There are several holes in the under side of the drum, and the bolt  $\Upsilon$  always takes the first one that it finds when the drum stops by the falling of the sollower upon the ram; until which stoppage, the bolt has not time to slip into any of the

holes.

This engine was placed upon a barge on the water, and so was easily conveyed to any place desired.—I never had the good fortune to see is, but drew this figure from a model which I made from a print of it; being not quite satisfied with the view which the print gives. I have been told that the ram was a ton weight, and that the guides b b, between which it was drawn up and let sall down, were 30 feet high. I suppose the great wheel may have had 100 cogs, and the trundle 10 staves or rounds; so that the sly would make 10 revolutions for one of the great wheel.



## PLATE X.



## LECT. V.

Of hydrostatics, and hydraulic machines.

THE science of bydrostatics treats of the nature, gravity, pressure, and motion of sluids in general; and of weighing solids in them.

A fluid is a body that yields to the least pref-Definifure or difference of preffures. Its particles are tion of a fo small, that they cannot be discerned by the best microscopes; they are hard, since no sluid, except air or steam, can be pressed into a less space than it naturally possesses; and they must be round and smooth, seeing they are so easily moved among one another.

All bodies, both fluid and folid, press downward by the force of gravity: but fluids have this wonderful property, that their pressure upward and sidewise is equal to their pressure downward; and this is always in proportion to their perpendicular height, without any regard to their quantity; for, as each particle is quite free to move, it will move toward that part or side on which the pressure is least. And hence, no particle or quantity of a sluid can be at rest, till it is every way equally pressed.

To shew by experiment that fluids press up-Plate X. ward as well as downward, let AB be a long Fig. 1. upright tube filled with water near to its top; Fluids and CD a small tube open at both ends, and press as much up-immersed into the water in the large one; if the ward as immersion be quick, you will see the water rise downin the small tube to the same height that it stands ward, in the great one, or until the surfaces of the

H 2 water

water in both are on the fame level: which shews that the water is pressed upward into the small tube by the weight of what is in the great one; otherwise it could never rise therein, contrary to its natural gravity; unless the diameter of the bore were fo fmall, that the attraction of the tube would raise the water; which will never happen, if the tube be as wide as that in a common barometer. And, as the water rifes no higher in the small tube than till its surface be on a level with the furface of the water in the great one, this shews that the pressure is not in proportion to the quantity of water in the great tube, but in proportion to its perpendicular height therein: for there is much more water in the great tube all around the small one, than what is raised to the same height in the small one, as it stands within the great.

Take out the small tube, and let the water run out of it; then it will be filled with air. Stop its upper end with the cork C, and it will be full of air all below the cork: this done, plunge it again to the bottom of the water in the great tube, and you will see the water rise up in it only to the height E; which shews that the air is a body, otherwise it could not hinder the water from rising up to the same height as it did before, namely, to A; and in so doing, it drove the air out at the top; but now the air is confined by the cork C: and it also shews that the air is a compressible body, for if it were not so, a drop of water could not enter into the tube.

The pressure of fluids being equal in all directions, it follows that the sides of a vessel are as much pressed by a fluid in it, all around in any given ring of points, as the sluid below that ring is pressed by the weight of all that stands above

it. Hence the pressure upon every point in the fides, immediately above the bottom, is equal to the pressure upon every point of the bottom. To shew this by experiment, let a hole be made at Fig. 2. e in the fide of the tube AB close by the bottom; and another hole of the same size in the bottom at C; then pour water into the tube, keeping it full as long as you choose the holes should run, and have two basons ready to receive the water that runs through the two holes, until you think there is enough in each bason; and you will find by measuring the quantities, that they are equal; which shews that the water run with equal fpeed through both holes: which it could not have done, if it had not been equally pressed through them both. For, if a hole of the same size be made in the side of the tube, as about f, and if all three are permitted to run together, you will find that the quantity run through the hole at f is much less than what has run in the same time through either of the holes C or e.

In the fame figure, let a tube be turned up from the bottom at e into the shape DE, and the hole at C be stopt with a cork. Then, pour water into the tube to any height, as Ag, and it will foout up in a jet EFG, nearly as high as it is kept in the tube AB, by continuing to pour in as much there as runs through the hole E; which will be the case while the surface Ag keeps at the same height. And if a little ball of cork G be laid upon the top of the jet, it will be fupported thereby, and dance upon it. The reason why the jet rifes not quite fo high as the furface of the water Ag, is owing to the refistance it meets with in the open air: for, if a tube, either great or fmall, was screwed upon the pipe at E, the H 3

water would rife in it until the furface of the water in both tubes were on the fame level; as

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The bydroftatic paradox.

Any quantity of a fluid, how small soever, may be made to balance and support any quantity, how great foever. This is deservedly termed the hydrostatical paradox, which we shall first shew by an experiment, and then account for it upon the principle above-mentioned; namely, that the pressure of fluids is directly as their perpendicular beight, without any regard to their quantity.

Fig. 3.

Let a small glass tube DCG, open throughout, and bended at B, be joined to the end of a great one A I at cd, where the great one is also open; fo that these tubes in their openings may freely communicate with each other. Then pour water through a finall necked funnel into the finall tube at H; this water will run through the joining of the tubes at cd, and rife up into the great tube; and if you continue pouring until the furface of the water comes to any part, as A, in the great tube, and then leave off, you will fee that the furface of the water in the small tube will be just as high, at D; so that the perpendicular height of the water will be the fame in both tubes, however small the one be in proportion to the other. This shews, that the small column DCG balances and supports the great column Acd: which it could not do if their pressures were not equal against one another in the recurved bottom at B .- If the small tube be made longer, and inclined in the situation GEF, the furface of the water in it will stand at F, on the fame level with the furface A in the great tube; that is, the water will have the same perpendicular height in both tubes, although the column in the small tube is longer than that in the great one;

the former being oblique, and the latter perpendicular.

Since then the pressure of fluids is directly as their perpendicular heights, without any regard to their quantities, it appears that whatever the figure or fize of vessels be, if they are of equal heights, and if the areas of their bottoms are equal, the pressures of equal heights of water are equal upon the bottoms of these vessels; even though the one should hold a thousand or ten thousand times as much water as would fill the To confirm this part of the hydroftatical Fig. 4, 5. paradox by an experiment, let two vessels be prepared of equal heights but very unequal contents, fuch as AB in Fig. 4. and AB in Fig. Let each veffel be open at both ends, and their bottoms Dd, Dd be of equal widths. a brass bottom CC be exactly fitted to each vesfel, not to go into it, but for it to stand upon; and let a piece of wet leather be put between each vessel and its brass bottom, for the sake of closeness. Join each bottom to its vessel by a hinge D, so that it may open like the lid of a box; and let each bottom be kept up to its vessel by equal weights E and E hung to lines which go over the pulleys F and F (whose blocks are fixed to the fides of the vessels at f) and the lines tied to hooks at d and d, fixed in the brass bottoms opposite to the hinges D and D. Things being thus prepared and fitted, hold the veffel AB (Fig. 5.) upright in your hands over a bason on a table, and cause water to be poured into the vessel slowly, till the pressure of the water bears down its bottom at the fide d, and raises the weight E; and then part of the water will run out at d. Mark the height at which the furface H of the water stood in the vessel, when the botwater would rife in it until the furface of the water in both tubes were on the fame level; as will be shewn by the next experiment.

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tom began to give way at d; and then, holding up the other vessel AB (Fig. 4.) in the same manner, cause water to be poured into it at H; and you will see that when the water rises to A in this vessel, just as high as it did in the former, its bottom will also give way at d, and it will lose

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part of the water.

The natural reason of this surprising phenomenon is, that fince all parts of a fluid at equal depths below the furface are equally pressed in all manner of directions, the water immediately below the fixed part Bf (Fig. 4.) will be preffed as much upward against its lower furface within the veffel, by the action of the column A g, as it would be by a column of the same height, and of any diameter whatever; (as was evident by the experiment with the tube, Fig. 3.) and therefore, fince action and reaction are equal and contrary to each other, the water immediately below the furface B f will be pressed as much downward by it, as if it was immediately touched and preffed by a column of the height g A, and of the diameter Bf: and therefore, the water in the cavity BDdf will be preffed as much downward upon its bottom CC, as the bottom of the other veffel (Fig. 5.) is pressed by all the water above it.

Fig. 4.

To illustrate this a little farther, let a hole be made at f in the fixed top Bf, and let a tube G be put into it; then, if water be poured into the tube A, it will (after filling the cavity Bd) rife up into the tube G, until it comes to a level with that in the tube A, which is manifestly owing to the pressure of the water in the tube A, upon that in the cavity of the vessel below it. Consequently, that part of the top Bf, in which the hole is now made, would, if corked up, be pressed

pressed upward with a force equal to the weight of all the water which is supported in the tube G: and the fame thing would hold at g, if a hole were made there. And so if the whole cover or top Bf were full of holes, and had tubes as high as the middle one Ag put into them, the water in each tube would rife to the same height as it is kept into the tube A, by pouring more into it, to make up the deficiency that it fustains by fupplying the others, until they are all full: and then the water in the tube A would support equal heights of water in all the rest of the tubes. Or, if all the tubes except A, or any other one, were taken away, and a large tube equal in diameter to the whole top Bf were placed upon it, and cemented to it, and then if water were poured into the tube that was left in either of the holes, it would afcend through all the rest of the holes, until it filled the large tube to the fame height that it stands in the small one, after a fufficient quantity had been poured into it: which shews, that the top Bf was pressed upward by the water under it, and before any hole was made in it, with a force equal to that wherewith it is now preffed downward by the weight of all the water above it in the great tube. And therefore, the re-action of the fixed top B f must be as great, in pressing the water downward upon the bottom CC, as the whole pressure of the water in the great tube would have been, if the top had been taken away, and the water in that tube left to press directly upon the water in the cavity B D d f.

Perhaps the best machine in the world for Fig. 6. demonstrating the upward pressure of sluids, is The hythe hydrostatic bellows A; which consists of two drostatic bellows. thick oval boards, each about 16 inches broad, and 18 inches long, covered with leather, to

open and shut like a common bellows, but without valves; only a pipe B, about three feet high, is fixed into the bellows at e. Let fome water be poured into the pipe at c, which will run into the bellows, and separate the boards a Then lay three weights b, c, d, each weighing 100 pounds, upon the upper board, and pour more water into the pipe B, which will run into the bellows, and raife up the board with all the weights upon it; and if the pipe be kept full, until the weights are raised as high as the leather which covers the bellows will allow them, the water will remain in the pipe, and support all the weights, even though it should weigh no more than a quarter of a pound, and they 300 pounds: nor will all their force be able to cause them to descend and sorce the water out at the

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The reason of this will be made evident, by confidering what has been already faid of the refult of the pressure of fluids of equal heights without any regard to the quantities. For, if a hole be made in the upper board, and a tube be put into it, the water will rife in the tube to the same height that it does in the pipe: and would rife as high (by fupplying the pipe) in as many tubes as the board could contain holes. fuppose only one hole to be made in any part of the board, of an equal diameter with the bore of the pipe B; and that the pipe holds just a quarter of a pound of water; if a person claps his finger upon the hole, and the pipe be filled with water, he will find his finger to be pressed upward with a force equal to a quarter of a pound. And as the fame preffure is equal upon all equal parts of the board, each part whole area is equal to the area of the hole, will be pressed upward with a force equal to that of a quarter of a pound: the fum

fum of all which preffures against the under side of an oval board 16 inches broad, and 18 inches long, will amount to 300 pounds; and therefore fo much weight will be raifed up and supported by a quarter of a pound of water in the pipe.

Hence, if a man stands upon the upper board, How a and blows into the bellows through the pipe B, man may he will raise himself upward upon the board: raise him-and the smaller the bore of the pipe is, the easier ward by he will be able to raise himself. And then, by his clapping his finger upon the top of the pipe, he breath. can support himself as long as he pleases; provided the bellows be air-tight fo as not to lofe what is blown into it.

This figure, I confess, ought to have been much larger than any other upon the plate; but it was not thought of, until all the rest were drawn; and it could not fo properly come into

any other plate.

Upon this principle of the upward pressure of Howfolid fluids, a piece of lead may be made to swim in lead may water, by immerfing it to a proper depth, and be made to fwim keeping the water from getting above it. CD be a glass tube, open throughout, and EFG a flat piece of lead, exactly fitted to the Fig. 7. lower end of the tube, not to go within it, but for it to stand upon; with a wet leather between the lead and the tube to make close work. this leaden bottom be half an inch thick, and held close to the tube by pulling the packthread IHL upward at L with one hand, while the tube is held in the other by the upper end C. In this fituation, let the tube be immerfed in water in the glass vessel A B, to the depth of fix inches below the furface of the water at K: and then, the leaden bottom EFG will be plunged to the depth of somewhat more than eleven times

Let in water.

its own thickness: holding the tube at that depth, you may let go the thread at L; and the lead will not fall from the tube, but will be kept to it by the upward pressure of the water below it, occasioned by the height of the water at K above the level of the lead. For as lead is 11.33 times as heavy as its bulk of water, and is in this experiment immerfed to a depth fomewhat more than 11.33 times its thickness, and no water getting into the tube between it and the lead, the column of water EabcG below the lead is pressed upward against it by the water KDEGL all around the tube; which water being a little more than 11.33 times as high as the lead is thick, is fufficient to balance and fupport the lead at the depth KE. If a little water be poured into the tube upon the lead, it will increase the weight upon the column of water under the lead, and cause the lead to fall from the tube to the bottom of the glass vessel, where it will lie in the fituation b d. Or, if the tube be raifed a little in the water, the lead will fall by its own weight, which will then be too great for the pressure of the water around the tube upon the column of water below it.

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How light be made to lie at the bottom of water.

Let two pieces of wood be planed quite flat, fo wood may as no water may get in between them when they are put together: let one of the pieces, as b d, be cemented to the bottom of the vessel AB (Fig. 7.) and the other piece be laid flat and close upon it, and held down to it by a flick, while water is poured into the veffel; then remove the stick, and the upper piece of wood will not rife from the lower one: for, as the upper one is pressed down both by its own weight and the weight of all the water over it, while the contrary preffure of the water is kept off by the wood

wood under it, it will lie as still as a stone would do in its place. But if it be raifed ever so little at any edge, some water will then get under it; which being acted upon by the water above, will immediately press it upward; and as it is lighter than its bulk of water, it will rife, and float upon the furface of the water.

All fluids weigh just as much in their own elements as they do in open air. To prove this by experiment, let as much shot be put into a phial, as, when corked, will make it fink in water: and, being thus charged, let it be weighed, first in air, and then in water, and the weights in both cases wrote down. Then, as the phial hangs fuspended in water, and counterpoifed, pull out the cork, that water may run into it, and it will descend, and pull down that end of the beam. This done, put as much weight into the opposite scale as will restore the equipoife; which weight will be found to answer exactly to the additional weight of the phial when it is again weighed in air, with the water in it.

The velocity with which water spouts out at a The velohole in the fide or bottom of a veffel, is as the city of fquare root \* of the depth or distance of the spouting hole below the furface of the water. For, in order to make double the quantity of a fluid run through one hole as through another of the fame fize, it will require four times the preffure of the other, and therefore must be four times the depth of the other below the furface of the water: and for the fame reason, three times the quantity running in an equal time through the

<sup>\*</sup> The square root of any number is that which being multiplied by itself produces the said number. Thus, 2 is the square root of 4, and 3 is the square root of 9: for 2 multiplied by 2 produces 4, and 3 multiplied by 3 produces 9, &cc.

Fig. 8.

fame fort of hole, must run with three times the velocity, which will require nine times the pressure; and consequently must be nine times as deep below the furface of the fluid: and fo on.—To prove this by an experiment, let two pipes, as C and g, of equal fized bores, be fixed into the fide of the veffel AB; the pipe g being four times as deep below the furface of the water at b in the vessel as the pipe C is: and while these pipes run, let water be constantly poured into the vessel, to keep the surface still at the fame height. Then, if a cup that holds a pint be fo placed as to receive the water that spouts from the pipe C, and at the same moment a cup that holds a quart be fo placed as to receive the water that spouts from the pipe g, both cups will be filled at the fame time by their respective pipes.

The horizontal distance to which **f**pout from

pipes.

The horizontal distance, to which a fluid will fpout from a horizontal pipe, in any part of the fide of an upright veffel below the furface of the water will fluid, is equal to twice the length of a perpendicular to the fide of the veffel, drawn from the mouth of the pipe to a femicircle described upon the altitude of the fluid: and therefore, the fluid will fpout to the greatest distance possible from a pipe, whose mouth is at the center of the femicircle; because a perpendicular to its diameter (supposed parallel to the side of the vessel) drawn from that point, is the longest that can possibly be drawn from any part of the diameter to the circumference of the semicircle. Thus, if the veffel A B be full of water, the horizontal pipe D be in the middle of its fide,

Fig. 8. and the femicircle Ndcb be described upon D as a center, with the radius or femidiameter D g N, or D f b, the perpendicular D d to the diameter NDb is the longest that can be drawn

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from any part of the diameter to the circumference Ndcb. And if the vessel be kept sull, the jet G will spout from the pipe D, to the horizontal distance NM, which is double the length of the perpendicular Dd. If two other pipes, as C and E, be fixed into the side of the vessel at equal distances above and below the pipe D, the perpendiculars Cc and Ee, from these pipes to the semicircle, will be equal; and the jets F and H spouting from them will each go to the horizontal distance NK; which is double the length of either of the equal perpendiculars Cc or Ee.

Fluids by their pressure may be conveyed over How wahills and vallies in bended pipes, to any height ter may not greater than the level of the spring from weyed whence they flow. But when they are designed over hills to be raised higher than the springs, forcing en-and valgines must be used; which shall be described lies. when we come to treat of pumps.

A syphon, generally used for decanting li- The syquors, is a bended pipe, whose legs are of un-phon. equal lengths; and the shortest leg must always be put into the liquor intended to be decanted, that the perpendicular altitude of the column of liquor in the other leg may be longer than the column in the immerfed leg, especially above the furface of the water. For, if both columns were equally high in that respect, the atmofphere, which preffes as much upward as downward, and therefore acts as much upward against the column in the leg that hangs without the veffel, as it acts downward upon the furface of the liquor in the veffel, would hinder the running of the liquor through the fyphon, even though it were brought over the bended part by fuction. So that there is nothing left to

Fig. 9.

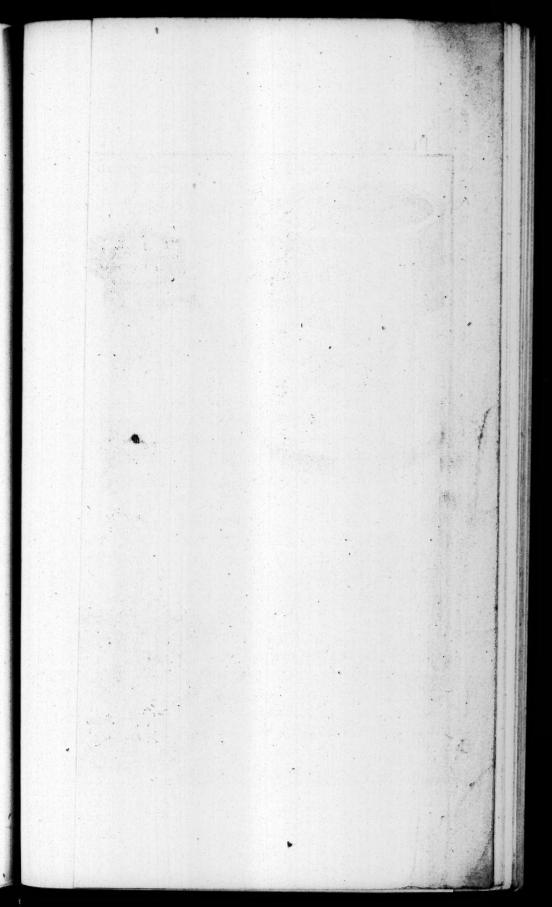
cause the motion of the liquor, but the superior weight of the column, in the longer leg, on account of its having the greater perpendicular

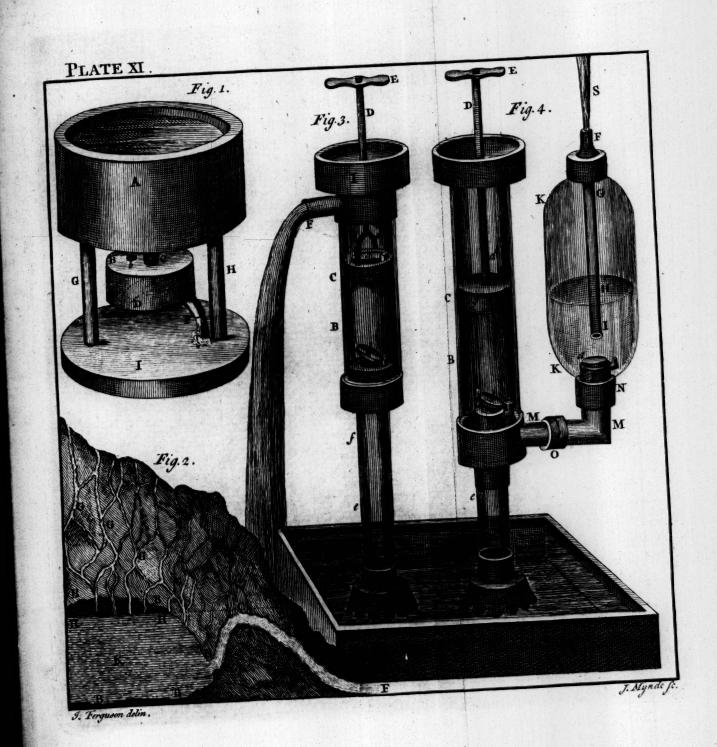
height.

Let D be a cup filled with water to C, and ABC a fyphon, whose shorter leg BCF is immerfed in the water from C to F. If the end of the other leg were no lower than the line AC, which is level with the furface of the water, the fyphon would not run, even though the air should be drawn out of it at the mouth A. although the fuction would draw fome water at first, yet the water would stop at the moment the fuction ceased; because the air would act as much upward against the water at A, as it acted downward for it by pressing on the surface at C. But if the leg AB comes down to G, and the air be drawn out at G by fuction, the water will immediately follow, and continue to run, until the furface of the water in the cup comes down to F; because, till then, the perpendicular height of the column BAG will be greater than that of the column CB; and confequently, its weight will be greater, until the furface comes down to F; and then the fyphon will stop, though the leg CF should reach to the bottom of the cup. For which reason, the leg that hangs without the cup is always made long enough to reach below the level of its bottom; as from d to E: and then, when the syphon is emptied of air by fuction at E, the water immediately follows, and by its continuity brings away the whole from the cup; just as pulling one end of a thread will make the whole clue follow.

If the perpendicular height of a syphon, from the surface of the water to its bended top at B,

be





be more than 33 feet, it will draw no water, even though the other leg were much longer, and the fyphon quite emptied of air; because the weight of a column of water 33 feet high, is equal to the weight of as thick a column of air, reaching from the surface of the earth to the top of the atmosphere; so that there will then be an equilibrium, and consequently, though there would be weight enough of air upon the surface C to make the water ascend in the leg CB almost to the height B, if the syphon were emptied of air, yet that weight would not be sufficient to force the water over the bend; and therefore, it could never be brought over into the leg B A G.

Let a hole be made quite through the bottom Fig. 10. of the cup A, and the longer leg of the bended Tantalus's fyphon DEBG be cemented into the hole, fo cup, that the end D of the shorter leg DE may almost touch the bottom of the cup within.

Then, if water be poured into this cup, it will rise in the shorter leg by its upward pressure, driving out the air all the way before it through the longer leg: and when the cup is filled above the bend of the syphon at F, the pressure of the water in the cup will force it over the bend of the syphon; and it will descend in the longer leg CBG, and run through the bottom, until the cup be emptied.

This is generally called *Tantalus's cup*, and the legs of the fyphon in it are almost close together; and a little hollow statue, or figure of a man, is sometimes put over the syphon to conceal it; the bend *E* being within the neck of the figure as high as the chin. So that poor thirsty *Tantalus* stands up to the chin in water, imagining it will rise a little higher, and he

may

may drink; but instead of that, when the water comes up to his chin, it immediately begins to descend, and so, as he cannot stoop to follow it, he is left as much pained with thirst as ever.

The fountain at command. Plate XI. Fig. 1.

The device called the fountain at command, acts upon the fame principle with the fyphon in the cup. Let two veffels A and B be joined together by the pipe C which opens into them Let A be open at top, B close both at top and bottom, fave only a small hole at b to let the air get out of the veffel B, and A be of fuch a fize, as to hold about fix times as much water as B. Let a fyphon DEF be foldered to the vessel B at e, so that the part D E e may be within the veffel, and F without it; the end D almost touching the bottom of the vessel, and the end F below the level of D: the vessel B hanging to A by the pipe C (foldered into both) and the whole supported by the pillars G and H upon the stand I. The bore of the pipe must be confiderably less than the bore of the syphon.

The whole being thus constructed, let the veffel A be filled with water, which will run through the pipe C, and fill the veffel B. B is filled above the top of the fyphon at E, the water will run through the fyphon, and be difcharged at F. But as the bore of the fyphon is larger than the bore of the pipe, the syphon will run faster than the pipe, and will soon empty the vessel B; upon which the water will cease from running through the syphon at F, until the pipe C refills the vessel B, and then it will begin to run as before. And thus the fyphon will continue to run and flop alternately, until all the water in the vessel A has run

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through the pipe C.—So that after a few trials, one may easily guess about what time the syphon will stop, and when it will begin to run: and then, to amuse others, he may call out stop,

or run, accordingly.

Upon this principle, we may easily account Interfor intermitting, or reciprocating springs. Let minting AA be part of a hill, within which there is a springs cavity BB; and from this cavity a vein or Fig. 2. channel running in the direction BCDE. The rain that falls upon the side of the hill will sink and strain through the small pores and crannies G, G, G, G; and fill the cavity with water K. When the water rises to the level HHC, the vein BCDE will be filled to C, and the water will run through CDF as through a syphon; which running will continue until the cavity be emptied, and then it will stop until the cavity be filled again.

The common pump (improperly called the fuck. The coming pump) with which we draw water out of mon pump, wells, is an engine both pneumatic and hydraulic. It consists of a pipe open at both ends, in which is a moveable piston or bucket, as big as the bore of the pipe in that part wherein it works; and is leathered round, so as to fit the bore exactly; and may be moved up and down, without suffering any air to come between it and the

pipe or pump barrel.

We shall explain the construction both of this and the forcing-pump by pictures of glass models, in which both the action of the pistons

and motion of the valves are fcen.

Hold the model DCBL upright in the vessel Fig. 3. of water K, the water being deep enough to rise at least as high as from A to L. The valve a on the moveable bucket G, and the valve b

on the fixed box H (which box quite fills the bore of the pipe or barrel at H) will each lie close, by its own weight, upon the hole in the bucket and box, until the engine begins to work. The valves are made of brass, and lined underneath with leather for covering the holes the more closely: and the bucket G is raised and depressed alternately by the handle E and rod D d, the bucket being supposed at B

before the working begins.

Take hold of the handle E, and thereby draw up the bucket from B to C, which will make room for the air in the pump all the way below the bucket to dilate itself, by which its fpring is weakened, and then its force is not equivalent to the weight or pressure of the outward air upon the water in the veffel K: and therefore, at the first stroke, the outward air will press up the water through the notched foot A, into the lower pipe, about as far as e: this will condense the rarefied air in the pipe between e and C to the fame state it was in before; and then, as its fpring within the pipe is equal to the force or pressure of the outward air, the water will rife no higher by the first stroke; and the valve b, which was raised a little by the dilatation of the air in the pipe, will fall, and stop the hole in the box H; and the furface of the water will stand at e. Then, depress the piston or bucket from C to B, and as the air in the part B cannot get back again through the valve b, it will (as the bucket defcends) raife the valve a, and fo make its way through the upper part of the barrel d into the open air. But upon raising the bucket G a second time, the air between it and the water in the lower pipe at a will be again left at liberty to

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fill a larger space; and so its spring being again weakened, the preffure of the outward air on the water in the veffel K will force more water up into the lower pipe from e to f; and when the bucket is at its greatest height C, the lower valve b will fall, and stop the hole in the box H as before. At the next stroke of the bucket or piston, the water will rife through the box H toward B, and then the valve b, which was raised by it, will fall when the bucket G is at its greatest height. Upon depressing the bucket again, the water cannot be pushed back through the valve b, which keeps close upon the hole while the pifton descends. And upon raising the pifton again, the outward pressure of the air will force the water up through H, where it will raife the valve, and follow the bucket to C. Upon the next depression of the bucket G, it will go down into the water in the barrel B; and as the water cannot be driven back through the new close valve b, it will raise the valve a as the bucket descends, and will be lifted up by the bucket when it is next raifed. And now, the whole space below the bucket being full, the water above it cannot fink when it is next depressed; but upon its depression, the valve a will rife to let the bucket go down; and when it is quite down, the valve a will fall by its weight, and stop the hole in the bucket. When the bucket is next raised, all the water above it will be lifted up, and begin to run off by the pipe F. And thus, by raifing and depressing the bucket alternately, there is still more water raifed by it; which getting above the pipe F, into the wide top I, will supply the pipe, and make it run with a continued ftream.

So, at every time the bucket is raised, the valve b rises, and the valve a falls; and at every time the bucket is depressed, the valve b falls, and a rises.

As it is the preffure of the air or atmosphere which causes the water to rise, and follow the piston or bucket G as it is drawn up; and fince a column of water 33 feet high is of equal weight with as thick a column of the atmosphere, from the earth to the very top of the air; therefore, the perpendicular height of the piston or bucket from the furface of the water in the well must always be less than 33 feet; otherwise the water will never get above the bucket. But, when the height is less, the pressure of the atmosphere will be greater than the weight of the water in the pump, and will therefore raise it above the bucket: and when the water has once got above the bucket, it may be lifted thereby to any height, if the rod D be made long enough, and a fufficient degree of strength be employed, to raise it with the weight of the water above the bucket.

The force required to work a pump will be as the height to which the water is raised, and as the square of the diameter of the pump-bore, in that part where the piston works. So that, if two pumps be of equal heights, and one of them be twice as wide in the bore as the other, the widest will raise four times as much water as the narrowest; and will therefore require four times as much strength to work it.

The wideness or narrowness of the pump, in any other part beside that in which the piston works, does not make the pump either more or less difficult to work, except what difference may arise from the friction of the water in the

bore;

bore; which is always greater in a narrow bore than in a wide one, because of the greater velo-

city of the water.

The pump-rod is never raifed directly by fuch a handle as E at the top, but by means of a lever, whose longer arm (at the end of which the power is applied) generally exceeds the length of the shorter arm five or fix times; and, by that means, it gives five or fix times as much advantage to the power. Upon these principles, it will be easy to find the dimensions of a pump that shall work with a given force, and draw water from any given depth. But, as thefe calculations have been generally neglected by pump-makers (either for want of skill or industry) the following table was calculated by the late ingenious Mr. Booth for their benefit. In this calculation, he supposed the handle of the pump to be a lever increasing the power five times; and had often found that a man can work a pump four inches diameter, and 30 feet high, and discharge 27½ gallons of water (English wine measure) in a minute. Now, if it be required to find the diameter of a pump, that shall raise water with the same ease from any other height above the furface of the well; look for that height in the first column, and overagainst it in the second you have the diameter or width of the pump; and in the third, you find the quantity of water which a man of ordinary strength can discharge in a minute.

<sup>\*</sup> I have taken the liberty to make a few alterations in Mr. Booth's numbers in the table, and to lengthen it out from 80 feet to 100.

Height of the pump above the furface of the well.	bore where the	Water discharged in a minute, English wine measure.	
Feet.	100 parts. Inches.	Pints. Gallons.	
10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95	6 .93 5 .66 4 .90 4 .38 4 .00 3 .70 3 .46 3 .27 3 .10 2 .95 2 .84 2 .72 2 .62 2 .53 2 .45 2 .38 2 .31 2 .25 2 .19	81 6 54 4 40 7 32 6 27 2 23 3 20 3 18 1 16 3 14 7 13 5 12 4 11 5 10 7 10 2 9 5 9 1 8 5 8 1	

The forcing pump.
Fig. 4.

The forcing pump raises water through the box H in the same manner as the common pump does, when the plunger or piston g is lifted up by the rod D d. But this plunger has no hole through it, to let the water in the barrel B C get above it, when it is depressed to B, and the valve b (which rose by the ascent of the water

water through the box H when the plunger g was drawn up) falls down and stops the hole in 'H, the moment that the plunger is raised to its greatest height. Therefore, as the water between the plunger g and box H can neither get through the plunger upon its descent, nor back again into the lower part of the pump Le, but has a free passage by the cavity around H into the pipe MM, which opens into the air-veffel KK at P; the water is forced through the pipe MM by the descent of the plunger, and driven into the air-veffel; and in running up through the pipe at P, it opens the valve a; which shuts at the moment the plunger begins to be raised, because the action of the water against the under fide of the valve then ceases.

The water, being thus forced into the airveffel KK by repeated strokes of the plunger, gets above the lower end of the pipe GHI, and then begins to condense the air in the vessel KK. For, as the pipe GH is fixed air-tight into the vessel below F, and the air has no way to get out of the veffel but through the mouth of the pipe at I, and cannot get out when the mouth I is covered with water, and is more and more condensed as the water rises upon the pipe, the air then begins to act forcibly by its fpring against the surface of the water at H: and this action drives the water up through the pipe IHGF, from whence it spouts in a jet S to a great height; and is supplied by alternately raising and depressing of the plunger g, which constantly forces the water that it raises through the valve H, along the pipe MM, into the airveffel KK.

The higher that the furface of the water H is raifed in the air-vessel, the less space will the

air be condensed into, which before filled that vessel; and therefore the force of its spring will be so much the stronger upon the water, and will drive it with the greater force through the pipe at F: and as the spring of the air continues while the plunger g is rising, the stream or jet S will be uniform, as long as the action of the plunger continues: and when the valve b opens, to let the water follow the plunger upward, the valve a shuts, to hinder the water, which is forced into the air-vessel, from running back by the pipe MM into the barrel of the pump.

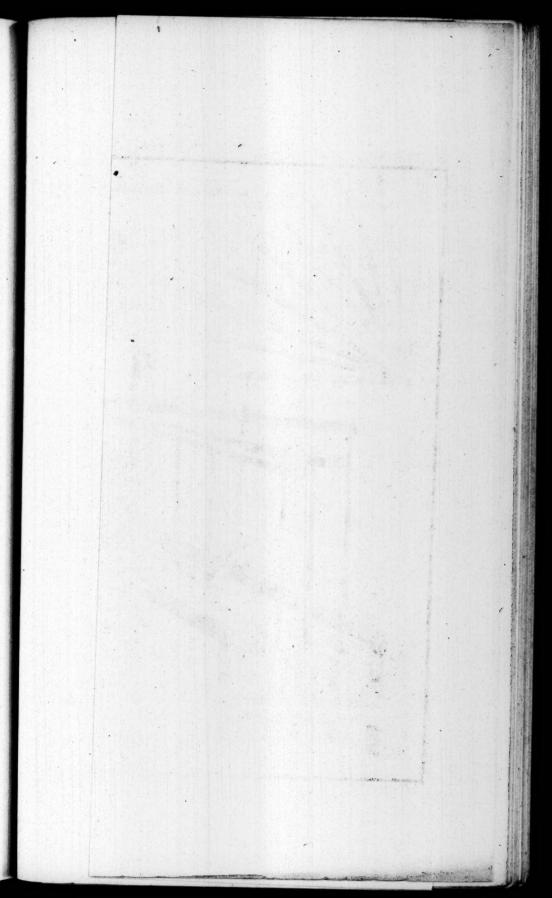
If there was no air-vessel to this engine, the pipe GHI would be joined to the pipe MMN at P; and then, the jet S would stop every time the plunger is raised, and run only when

the plunger is depressed.

Mr. Newsham's water-engine, for extinguishing fire, consists of two forcing pumps, which alternately drive water into a close vessel of air and by forcing the water into that vessel, the air in it is thereby condensed, and compresses the water so strongly, that it rushes out with great impetuosity and force through a pipe that comes down into it; and makes a continued uniform stream by the condensation of the air upon its surface in the vessel.

By means of forcing-pumps, water may be raifed to any height above the level of a river or fpring; and machines may be contrived to work these pumps, either by a running stream, a fall of water, or by horses. An instance in each fort will be sufficient to shew the method.

Plate XII. First, by a running stream, or a fall of wa-Fig. 1. ter. Let AA be a wheel, turned by the fall of water BB; and have any number of cranks (sup-



(suppose six) as C, D, E, F, G, H, on its axis, according to the strength of the fall of water, and the height to which the water is intended to be raised by the engine. As the whe ! turns round, these cranks move the levers c, d, e, f, g, b, A pump up and down, by the iron rods i, k, l, m, n, o; engine to which alternately raise and depress the pistons by go by the other iron rods p, q, r, f, t, u, w, x, y, in twelve pumps; nine whereof, as L, M, N, O, P, Q, R, S, T, appear in the plate; the other three being hid behind the work at V. And as pipes may go from all thefe pumps, to convey the water (drawn up by them to a small height) into a close ciftern, from which the main pipe goes off, the water will be forced into this ciftern by the descent of the pistons. And as each pipe, going from its respective pump into the cistern, has a valve at its end in the ciftern, these valves will hinder the return of the water by the pipes; and therefore, when the ciftern is once full, each piston upon its descent will force the water (conveyed into the ciftern by a former stroke) up the main pipe, to the height the engine was intended to raise it: which height depends upon the quantity raised, and the power that turns the wheel. When the power upon the wheel is leffened by any defect of the quantity of water turning it, a proportionable number of the pumps may be fet aside, by disengaging their rods from the vibrating levers.

This figure is a representation of the engine erected at *Blenbeim* for the Duke of *Marlborough*, by the late ingenious Mr. *Aldersea*. The waterwheel is  $7\frac{1}{2}$  feet in diameter, according to Mr.

Switzer's account in his Hydraulics.

When fuch a machine is placed in a stream that runs upon a small declivity, the motion of

the levers and action of the pumps will be but flow; fince the wheel must go once round for each stroke of the pumps. But, when there is a large body of flow running water, a cog or fpurwheel may be placed upon each fide of the water-wheel A A, upon its axis, to turn a trundle upon each fide; the cranks being upon the axis of the trundle. And by proportioning the cogwheels to the trundles, the motion of the pumps may be made quicker, according to the quantity and strength of the water upon the first wheel; which may be as great as the workman pleases; according to the length and breadth of the floatboards or wings of the wheel. In this manner, the engine for raifing water at London-Bridge is constructed; in which, the water-wheel is 20 feet diameter, and the floats 14 feet long.

A pump engine to go by horses.

Fig. 2.

Where a stream or fall of water cannot be had, and gentlemen want to have water raised, and brought to their houses from a rivulet or spring; this may be effected by a horse-engine, working three forcing pumps which stand in a refervoir filled by the fpring or rivulet: the piftons being moved up and down in the pumps by means of a triple crank ABC, which, as it is turned round by the trundle G, raises and depresses the rods D, E, F. The trundle may be turned by fuch a wheel as F in Fig. 1. of Plate VIII. having levers y, y, y, on its upright axle, to which horses may be joined for working the engine. the wheel has three times as many cogs as the trundle has staves or rounds, the trundle and cranks will make three revolutions for every one of the wheel: and as each crank will fetch a stroke in the time it goes round, the three cranks will make nine strokes for every turn of the great wheel.

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I Fan The cranks should be made of cast iron, be cause that will not bend; and they should each make an angle of 120 with both of the others, as at a, b, c; which is (as it were) a view of their Plate XII. radii, in looking endwise at the axis: and then Fig. 2. there will be always one or other of them going downward, which will push the water forward with a continued stream into the main pipe. For, when b is almost at its lowest position, and is therefore just beginning to lose its action upon the piston which it moves, c is beginning to move downward, which will by its piston continue the propelling force upon the water: and when c is come down to the position of b, a will be in the position of c.

The more perpendicularly the pifton rods move up and down in the pumps, the freer and better will their strokes be: but a little deviation from the perpendicular will not be material. Therefore, when the pump-rods D, E, and F, go down into a deep well, they may be moved directly by the cranks, as is done in a very good horse-engine of this fort at the late Sir James Creed's at Greenwich, which forces up water about 64 feet from a well under ground, to a reservoir on the top of his house. But when the cranks are only at a small height above the pumps, the pistons must be moved by vibrating levers, as in the above engine at Blenbeim: and the longer the levers are, the nearer will the strokes be to a

perpendicular.

Let us suppose, that in such an engine as Sir The quanfames Creed's, the great wheel is 12 feet diametity of ter, the trundle 4 feet, and the radius or length may be of each crank 9 inches, working a piston in its raised by pump. Let there be three pumps in all, and the a horsebore of each pump be four inches diameter. engine.

Then,

Then, if the great wheel has three times as many cogs as the trundle has flaves, the trundle and cranks will go three times round for each revolution of the horses and wheel, and the three cranks will make nine strokes of the pumps in that time, each stroke being 18 inches (or double the length of the crank) in a four-inch bore. Let the diameter of the horse-walk be 18 feet, and the perpendicular height to which the water is raised above the surface of the well be 64 feet.

If the horses go at the rate of two miles an hour (which is very moderate walking) they will turn the great wheel 187 times round in an

hour.

In each turn of the wheel the pistons make 9 strokes in the pumps, which amount to 1683 in an hour.

Each stroke raises a column of water 18 inches long, and sour inches thick, in the pump-barrels; which column, upon the descent of the piston, is forced into the main pipe, whose perpendicular altitude above the surface of the well is 64 feet.

Now, fince a column of water 18 inches long, and 4 inches thick, contains 226.18 cubic inches, this number multiplied by 1683 (the strokes in an hour) gives 380661 for the number of cubic inches of water raised in an hour.

A gallon, in wine measure, contains 231 cubic inches, by which divide 380661, and it quotes 1468 in round numbers, for the number of gallons raised in an hour; which, divided by 63, gives 26½ hogsheads.—If the horses go faster, the quantity raised will be so much the greater.

In this calculation it is supposed that no water is wasted by the engine. But as no forcing engine can be supposed to lose less than a fifth

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part of the calculated quantity of water, between the piftons and barrels, and by the opening and flutting of the valves, the horses ought to walk almost 2½ miles per hour, to fetch up this loss.

A column of water 4 inches thick, and 64 feet high, weighs 349 pounds avoirdupoife, or 424 pounds troy; and this weight, together with the friction of the engine, is the resistance that must be overcome by the strength of the horses.

The horse-tackle should be so contrived, that the horses may rather push on than drag the levers after them. For if they draw, in going round the walk, the outside leather straps will rub against their sides and hams; which will hinder them from drawing at right angles to the levers, and so make them pull at a disadvantage. But if they push the levers before their breasts, instead of dragging them, they can always walk at right angles to these levers.

It is no ways material what the diameter of the main or conduct pipe be: for the whole refistance of the water therein, against the horses, will be according to the height to which it is raised, and the diameter of that part of the pump in which the piston works, as we have already observed. So that by the same pump, an equal quantity of water may be raised in (and consequently made to run from) a pipe of a foot diameter, with the same ease as in a pipe of five or six inches: or rather with more ease, because its velocity in a large pipe will be less than in a small one; and therefore its friction against the sides of the pipe will be less also.

And the force required to raise water depends not upon the length of the pipe, but upon the perpendicular height to which it is raised therein above the level of the spring. So that the same

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Fig. 3.

force, which would raise water to the height AB in the upright pipe AiklmnopqB, will raise it to the same height or level BIH in the oblique pipe AEFGH. For the pressure of the water at the end A of the latter, is no more than its pref-

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The weight or preffure of water at the lower end of the pipe, is always as the fine of the angle to which the pipe is elevated above the level parallel to the horizon. For, although the water in the upright pipe AB would require a force applied immediately to the lower end A equal to the weight of all the water in it, to fupport the water, and a little more to drive it up, and out of the pipe; yet, if that pipe be inclined from its upright position to an angle of 80 degrees (as in A 80) the force required to support or to raife the fame cylinder of water will then be as much less, as the fine 80 b is less than the radius AB; or as the fine of 80 degrees is less than the fine of 90. And fo, decreafing as the fine of the angle of elevation lessens, until it arrives at its level AC or place of rest, where the force of the water is nothing at either end of the For, although the absolute weight of the water is the fame in all positions, yet its pressure at the lower end decreases, as the fine of the angle of elevation decreases; as will appear plainly by a farther confideration of the figure.

Let two pipes, AB and AC, of equal lengths and bores, join each other at A; and let the pipe A B be divided into 100 equal parts, as the scale S is; whose length is equal to the length of the pipe.—Upon this length, as a radius, describe the quadrant BCD, and divide it into 90 equal

parts or degrees.

Let the pipe AC be elevated to 10 degrees upon

upon the quadrant, and filled with water; then, part of the water that is in it will rise in the pipe AB, and if it be kept full of water, it will raise the water in the pipe AB from A to i; that is, to a level i 10 with the mouth of the pipe at 10: and the upright line a 10, equal to Ai, will be the sine of 10 degrees elevation; which being measured upon the scale S, will be about 17.4 of such parts as the pipe contains 100 in length: and therefore, the force or pressure of the water at A, in the pipe A 10, will be to the force or pressure at A in the pipe AB, as 17.4 to 100.

Let the same pipe be elevated to 20 degrees in the quadrant, and if it be kept full of water, part of that water will run into the pipe AB, and rise therein to the height Ak, which is equal to the length of the upright line b 20, or to the sine of 20 degrees elevation; which, being measured upon the scale S, will be 34.2 of such parts as the pipe contains too in length. And therefore, the pressure of the water at A, in the sull pipe A 20, will be to its pressure, if that pipe were raised to the perpendicular situa-

thon AB, as 34.2 to 100. Elevate the pipe to the position A 30 on the quadrant, and if it be supplied with water, the water will rise from it, into the pipe AB, to the height Al, or to the same level with the mouth of the pipe at 30. The sine of this elevation, or of the angle of 30 degrees, is  $\epsilon$  30; which is just equal to half the length of the pipe, or to 50 of such parts of the scale, as the length of the pipe contains 100. Therefore, the pressure of the water at A, in a pipe elevated 30 degrees above the horizontal level, will be equal to one half of what it would be, if the same pipe stood upright in the situation AB.

And

## Of Hydraulic Engines.

And thus, by elevating the pipe to 40, 50, 60, 70, and 80 degrees on the quadrant, the fines of these elevations will be d 40, e 50, f 60, g 70, and b 80; which will be equal to the heights Am, An, Ao, Ap, and Aq: and these

Sine of	Parts	Sine of	Parts	Sine of	Parts
D.1	17	D.31	515	D.61	875
2	35	32	530	62	883
3	52	33	545	63	891
4	70	34	559	64	899
5	87	35	573	65	906
5 6	104	36	588	66	913
	122	37	602	67	920
7 8	139	38	616	68	927
9	156	39	629	69	934
IO	174	40	643	70	940
11	191	41	656	71	945
12	208	42	669	72	951
13	225	43	682	73	956
14	242	44	695	74	961
15	259	45	707	75	966
16	276	46	719	76	970
17	292	47	731	77	974
18	309	48	743	78	978
19	325	49	755	79	982
20	342	50	766	80	985
21	358	51	777	81	988
22	375	52	788	82	990
23	391	53	799	83	992
24	407	54	809	84	994
25	423	55	819	85	996
26	438	56	829	86	997
27	454	57	839	87	998
28	469	58	848	88	999
29	485	59	857	89	1000
30	500	60	866	90	1000

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heights measured upon the scale S will be 64.3, 76.6, 86.6, 94.0, and 98.5; which express the pressures at A in all these elevations, considering the pressure in the upright pipe AB as 100.

Because it may be of use to have the lengths of all the sines of a quadrant from o degrees to 90, we have given the foregoing table, shewing the length of the sine of every degree in such parts as the whole pipe (equal to the radius of the quadrant) contains 1000. Then the sines will be integral or whole parts in length. But if you suppose the length of the pipe to be divided only into 100 equal parts, the last sigure of each part or sine must be cut off as a decimal; and then those which remain at the less hand of this separation will be integral or whole parts.

Thus, if the radius of the quadrant (supposed to be equal to the length of the pipe AC) be divided into 1000 equal parts, and the elevation be 45 degrees, the sine of that elevation will be equal to 707 of these parts: but if the radius be divided only into 100 equal parts, the same sine will be only 70.7 or  $70\frac{7}{10}$  of these parts. For, as 1000 is to 707, so is 100 to

70.7.

As it is of great importance to all engine-makers, to know what quantity and weight of water will be contained in an upright round pipe of a given diameter and height; so as by knowing what weight is to be raised, they may proportion their engines to the force which they can afford to work them; we shall subjoin tables shewing the number of cubic inches of water contained in an upright pipe of a round bore, of any diameter from one inch to six and K 2 a half;

a half; and of any height from one foot to two hundred: together with the weight of the faid number of cubic inches, both in troy and avoirdupoise ounces. The number of cubic inches divided by 231, will reduce the water to gallons in wine measure; and divided by 282, will reduce it to the measure of ale gallons. Also, the troy ounces divided by 12, will reduce the weight to troy pounds: and the avoirdupoise ounces divided by 16, will reduce the weight to

avoirdupoise pounds.

And here I must repeat it again, that the weight or pressure of the water acting against the power that works the engine, must always be estimated according to the perpendicular height to which it is to be raifed, without any regard to the length of the conduct-pipe, when it has an oblique position; and as if the diameter of that pipe were just equal to the diameter of that part of the pump in which the pifton Thus, by the following tables, the pressure of the water, against an engine whose pump is of a 41 inch bore, and the perpendicular height of the water in the conduct-pipe is 80 feet, will be equal to 8057.5 troy ounces, and to 8848.2 avoirdupoise ounces; which makes 671.4 troy pounds, and 553 avoirdupoise.

For any bore whose diameter exceeds 6½ inches, multiply the numbers on the following page, against any height (belonging to 1 inch diameter) by the square of the diameter of the given bore, and the products will be the number of cubic inches, troy ounces, and avoirdupoise ounces of water, that the given bore will

contain.

1 Inch diameter.			
Feet high.	Quantity in cubic inches.	Weight in troy ounces.	In avoir- dupoife ounces.
1 2 3 4 5	9.42 11.85 28.27 37.70 47.12	4.97 9.9 <b>5</b> 14.92 19.89 24.87	5,46 10.92 16.38 21.85 27.31
6 7 8 9	56.55 65.97 75.40 84.82 94.25	29.84 34.82 39.79 44.76 49.74	32.77 38.23 43.69 49.16 54.62
20 30 40 50	188.49 282.74 376.99 471.24 565.49	99.48 149.21 198.95 248.69 298.43	109.24 163.86 218.47 273.09 327.71
70 80 90 100 200	659.73 753.98 848.23 942.48 1884.96	348.17 397.90 447.64 497.38 994.76	382.33 436.95 491.57 546.19 1092.38

EXAMPLE, Required the number of cubic inches, and the weight of the water, in an upright pipe 278 feet high, and 1½ inch diameter?

Here the nearest fingle decimal figure is only taken into the account: and the whole being reduced by division, amounts to  $25\frac{1}{2}$  wine gallons in measure; to  $259\frac{1}{4}$  pounds troy, and to  $213\frac{1}{2}$  pounds avoirdupoise.

Cubic Troy Avoird. Feet inches oz. oz. 200-4241.1-2238.2-2457.8 70-1484.4-783.3-860.2 8-169.6-89.5-98.3

to 2594 pounds troy, and Anf. 278-5895.1-3111.0-3416.3

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These

1½ Inch diameter.				
Feet high.	Quantity in cubic inches.	Weight in troy ounces.	In avoir- dupoife ounces.	
1	21.21	11.19	12.29	
2	42.41	22.38	24.58	
3	63.62	33.57	36.87	
4	84.82	44.76	49.16	
5	106.03	55.95	61.45	
6 7 8 9	127.23 147.44 169.65 190.85 212.06	67.15 78.34 89.53 100.72	73.73 86.02 98.31 110.60 122.89	
20	424.12	223.82	245.78	
30	636.17	335.73	368.68	
40	848.23	447.64	491.57	
50	1060.29	559.55	614.46	
60	1272.35	671.46	737.35	
70	1484.40	783.37	860.24	
80	1696.46	895.28	983.14	
90	1908.52	1007.19	11c6.03	
100	2120.58	1119.10	1228.92	
200	4241.15	2238.20	2457.84	

These tables were at first calculated to fix decimal places for the sake of exactness; but in transcribing them there are no more than two decimal figures taken into the account, and sometimes but one; because there is no necessity

for

	2 Inch	es diamete	r.
Feet high.	Quantity in cubic inches.	Weight in troy ounces.	In avoir- dupoife ounces.
1	37.7°	19.89	21.85
2	75.4°	39.79	43.69
3.	113.1°	59.68	65.54
4	150.8°	79.58	87.39
5	188.5°	99.47	109.24
6 7 8 9	226.19 263.89 301.59 339.29 376.99	119.37 139.26 159.16 179.06 198.95	131.08 152.93 174.78 196.63 218.47
20	753.98	397.90	436.95
30	1130.97	596.85	655.42
40	1507.97	795.80	873.90
50	1884.96	994.75	1092.37
60	2261.95	1193.70	1310.85
70	2638.94	1392.65	1529.32
80	3015.93	1591.60	1747.80
90	3392.92	1790.56	1966.27
100	3769.91	1989.51	2184.75
200	7539.82	3979.00	4369.50

for computing to hundredth parts of an inch or of an ounce in practice. And as they never appeared in print before, it may not be amiss to give the reader an account of the principles upon which they were constructed.

2½ Inches diameter.				
Feet high.	Quantity in cubic inches.	Weight in troy ounces.	In avoir- dupoife ounces.	
1	58.90	31.08	34.14	
2	117.81	62.17	68.27	
3	176.71	93.26	102.41	
4	235.62	124.34	136.55	
5	294.52	155.43	170.68	
6 7 8 9	353.43 412.33 471.24 530.14 589.05	186.52 217.60 248.69 279.77 310.86	204.82 238.96 273.09 307.23 341.37	
20	1178.10	621.72	682.73	
30	1767.15	932 58	1024.10	
40	2356.20	1243.44	1365.47	
50	2545.25	1554.30	1706.83	
60	3534.29	1865.16	2048.20	
70	4123.34	2176.02	2389.57	
80	4712.39	2486.88	2730.94	
90	5301.44	2797.74	3072.30	
100	5890.49	3108.60	2413.67	
200	11780.98	6217.20	4827.34	

The folidity of cylinders are found by multiplying the areas of their bases by their altitudes. And Archimedes gives the following proportion for finding the area of a circle, and the solidity of a cylinder raised upon that circle:

As

	3 Inch	es diamete	r.
Feet high.	Quantity in cubic inches.	Weight in troy ounces.	In avoir- dupoise ounces.
I 2	84.8	44.76	49.16
	169.6	89.53	98.31
3 4 5	254.5	134.29	147.47
	239.3	179.06	196.63
	424.1	223.82	245.78
6 7 8 9	508.9 593.7 698.6 763.4 848.2	268.58 313.35 358.11 402.87 447.64	294.94 344.10 393.25 442.41 491.57
20	1696.5	895.28	983.14
30	2544.7	1342.92	1474.70
40	3392.9	1790.56	1966.27
50	4241.1	2238.19	2457.84
60	5089.4	2685.83	2949.41
70	5937.6	3133.47	3440.98
80	6785.8	3581.11	393 <b>2.5</b> 5
90	7634.1	4028.75	4424.12
100	8482.3	4476.39	4915.68
200	16964.6	8952.78	9831.36

As 1 is to 0.785399, so is the square of the diameter to the area of the circle. And as 1 is to 0.785399, so is the square of the diameter multiplied by the height to the solidity of the cylinder. By this analogy the solid inches and parts

3½ Inches diameter.			
Feet high.	Quantity in cubic inches.	Weight in troy ounces.	In avoir- dupoife ounces.
1	115.4	60.9	66.9
2	230.9	121.8	133.8
3	346.4	182.8	200.7
4	461.8	243.7	267.6
5	577.3	304.6	334.5
6 7 8 9	692.7 808.2 923.6 1039.1 1154.5	365.6 426.5 487.4 548.4 609.3	401.4 468.4 535.3 602.2 669.1
20	2309.1	1218.6	1338.2
30	3463.6	1827.9	2007.2
40	4618.1	2437.1	2676.3
50	5772.7	3046.4	3345.4
60	6927.2	3655.7	4014.5
70	8081.8	4265.0	4683.6
80	9236.3	4874.3	5352.6
90	10390.8	5483.6	6021.7
100	11545.4	6092.9	6690.8
200	23090.7	12185.7	13381.5

parts of an inch in the tables are calculated to a cylinder 200 feet high, of any diameter from 1 inch to  $6\frac{1}{2}$ , and may be continued at pleasure.

And as to the weight of a cubic foot of running water, it has been often found upon trial, by Dr.

Dr. troy, poife mche conta

	4 Inches diameter.						
Feet high.	Quantity in cubic inches.	Weight in troy ounces.	In avoir- dupoife ounces.				
3 4 5	150.8 301,6 452.4 603.2 754.0	79.6 159.2 238.7 318.3 397.9	87.4 174.8 262.2 349.6 436.9				
6 7 8 9	904.8 1055.6 1206.4 1357.2 1508.0	477.5 557.1 636.6 716.2 795.8	524.3 611.7 699.1 786.5 873.9				
20 30 40 50 60	2115.9 4523.9 6031.9 7539.8 9047.8	1591.6 2387.4 3183.2 3997.0 4774.8	1747.8 2621.7 3495.6 4369.5 5243.4				
70 80 90 100 200	105 <b>55.8</b> 120 <b>63.7</b> 13571.7 15079.7 30159.3	5570.6 6366.4 7162.2 7958.0 15916.0	6117.3 6991.2 7865.1 8739.0				

Dr. Wyberd and others, to be 76 pounds troy, which is equal to 62.5 pounds avoirdu- The poise. Therefore, fince there are 1728 cubic weight of inches in a cubic foot, a troy ounce of water running contains 1.8949 cubic inch; and an avoirdupoise water.

## Hydrostatical Tables.

	4½ Inches diameter.						
Feet high.	Quantity in cubic inches.	Weight in troy ounces.	In avoir- dupoife ounces.				
1	190.8	100.7	110.6				
2	381.7	201.4	221.2				
3	572.6	302.2	331.8				
4	763.4	402.9	442.4				
5	954.3	503.6	553.0				
6 7 8 9	1145.1 1338.0 1526.8 1717.7 1908.5	604.3 705.0 805.7 906.5 1007.2	663.6 774.2 884.8 995.4 1106.0				
20	3817.0	2014.4	2212.1				
30	5725.6	3021.6	3818.1				
40	7634.1	4028.7	4424.1				
50	9542.6	5035.9	5530.1				
60	11451.1	6043.1	6636.2				
70	13359.6	7050.3	7742.2				
80	1526 <b>8</b> .2	8057.5	8848.2				
90	171 <b>7</b> 6.7	9064.7	9954.3				
100	19085.2	10071.9	11060.3				
200	38170.4	20143.8	22120.6				

ounce of water 1.72556 cubic inch. Confequently, if the number of cubic inches contained in any given cylinder, be divided by 1.8949, it will give the weight in troy ounces; and divided by 1.72556, will give the weight

	5 Inches diameter.						
Feet high.	Quantity in cubic inches.	in cubic in troy					
1 2 3 4 5	235.6 471.2 706.6 942.5 1178.1	124.3 248.7 373.0 497.4 621.7	136.5 273.1 409.6 546.2 682.7				
6 7 8 9	1413.7 1649.3 1885.0 2120.6 2356.2	746.1 870.4 994.8 1119.1 1243.4	819.3 955.8 1092.4 1228.9 1365.5				
20 30 40 50	4712.4 7068,6 9424.8 11780.0 14137.2	2486.9 373°.3 4973.8 6217.2 746°.6	2730.9 4096,4 5461.9 6827.3 8192.8				
70 80 90 100 200	16493.4 18849.6 21205.8 23562.0 47124.0	8704.1 9947.5 11191.0 12434.4 24868.3	9558.3 10923.7 12289.2 13654.7 27309.3				

in avoirdupoise ounces. By this method, the weights shewn in the tables were calculated; and are near enough for any common practice.

The fire-engine comes next in order to be ex- The fireplained; but as it would be difficult, even by engine.

# Hydrostatical Tables.

	5½ Inches diameter.					
Feet high.	Quantity in cubic inches.	Weight in troy ounces.	In avoir- dupoife ounces.			
1	285.1	150.5	164.3			
2	570.2	300.9	328.5			
3	855.3	451.4	492.8			
4	1140.4	601.8	657.1			
5	1425.5	752.3	821.3			
6 7 8 9	1710.6 1995.7 2280.8 2565.9 2851.0	902.7 1053.2 1203.6 1354.1 1504.6	985.6 1149.9 1314.2 1478.4 1642.7			
20	5702.0	3009.1	3285.4			
30	8553.0	4513.7	4928.1			
40	11404.0	6018.2	6570.8			
50	14255.0	7522.8	8213.5			
60	17106.0	9027.4	9856.2			
70	19957.0	10531.9	11498.9			
80	22808.0	12036.5	13141.6			
90	25659.0	13541.1	14784.3			
100	28510.0	15045.6	16426.9			
200	57020.0	30091.2	32853.9			

the best plates, to give a particular description of its several parts, so as to make the whole intelligible, I shall only explain the principles upon which it is constructed.

1. What-

6 Inches diameter.						
Feet high.	Quantity in cubic inches.	Weight in troy ounces.	In avoir- dupoise ounces.			
1	339.3	179.1	196.6			
2	678.6	358.1	393.3			
3	1017.9	537.2	589.9			
4	1357.2	716.2	786.5			
5	1696.5	895.3	983.1			
6 7 8 9	2035.7 2375.0 2714.3 3053.6 3392.9	1074.3 1253.4 1432.4 1611.5 1790.6	1179.8 1376.4 1573.0 1769.6 1966.3			
20	6785.8	3581.1	3932.5			
30	10178.8	5371.7	5898.8			
40	13571.7	7162.2	7865.1			
50	16964.6	8952.8	9831.4			
60	20357.5	10743.3	11797.6			
70	23750.5	12533.9	13763.9			
80	24143.7	14324.4	15730.2			
90	30536.3	16115.0	17696.5			
100	33929.2	17905.6	19662.7			
200	67858.4	35811.2	39325.4			

the pump-rod must be loaded with weights sufficient for that purpose, if it be done by a forcing pump, as is generally the case; and the power

	6½ Inches diameter.						
Feet high.	Quantity	Weight	In avoir-				
	in cubic	in troy	dupoife				
	inches.	ounces.	ounces.				
1	398.2	210.1	230.7				
2	797.4	420.3	461.4				
3	1195.6	630.4	692.1				
4	1593.8	840.6	922.8				
5	1991.9	1050.8	1153.6				
6 7 8 9	2390.1 2788.3 3186.5 3584.7 3982.9	1260.9 1471.1 1681.2 1891.3 2101.5	1384.3 1615.0 1845.7 2076.4 2307.1				
20	7965.8	4202.9	4614.3				
30	11948.8	6304.4	6921.4				
40	15931.7	8405.9	9228.6				
50	19914.6	10507.4	11535.7				
60	23897.9	12608.9	13842.9				
70	27880.5	14710.4	16150.0				
80	31863.4	16811.8	18457.2				
90	35846.3	18913.3	20764.3				
100	39829.3	21014.8	23071.5				
200	79658.6	42029.6	46143.0				

power of the engine must be sufficient for the weight of the rod, in order to bring it up.

2. It is known, that the atmosphere presses upon the surface of the earth with a force equal to 15 pounds upon every square inch.

3. When

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3. When water is heated to a certain degree, the particles thereof repel one another, and conflitute an elastic sluid, which is generally called seam or vapour.

4. Hot steam is very elastic; and when it is cooled by any means, particularly by its being mixed with cold water, its elasticity is destroyed immediately, and it is reduced to water again.

- 5. If a veffel be filled with hot steam, and then closed, so as to keep out the external air, and all other fluids; when that steam is by any means condensed, cooled, or reduced to water, that water will fall to the bottom of the vessel; and the cavity of the vessel will be almost a perfect vacuum.
- 6. Whenever a vacuum is made in any veffel, the air by its weight will endeavour to rush into the veffel, or to drive in any other body that will give way to its pressure; as may be easily seen by a common syringe. For, if you stop the bottom of a syringe, and then draw up the piston, if it be so tight as to drive out all the air before it, and leave a vacuum within the syringe, the piston being let go will be driven down with a great force.

7. The force with which the pifton is driven down, when there is a vacuum under it, will be as the fquare of the diameter of the bore in the fyringe. That is to fay, it will be driven down with four times as much force in a fyringe of a two-inch bore, as in a fyringe of one inch: for the areas of circles are always as the fquares of their diameters.

8. The pressure of the atmosphere being equal to 15 pounds upon a square inch, it will be almost equal to 12 pounds upon a circular inch. So that if the bore of the syringe

be round, and one inch in diameter, the piston will be prest down into it by a force nearly equal to 12 pounds: but if the bore be two inches diameter, the piston will be prest down with four times that force.

And hence it is easy to find with what force the atmosphere presses upon any given number

either of fquare or circular inches.

These being the principles upon which this engine is constructed, we shall next describe the chief working parts of it: which are, 1. A boiler. 2. A cylinder and piston. 3. A beam or lever.

The boiler is a large vessel made of iron or copper; and commonly so big as to contain

about 2000 gallons.

The cylinder is about 40 inches diameter, bored fo fmooth, and its leathered pifton fitting fo close, that little or no water can get between the pifton and fides of the cylinder.

Things being thus prepared, the cylinder is placed upright, and the shank of the piston is fixed to one end of the beam, which turns on a

center like a common balance.

The boiler is placed under the cylinder, with a communication between them, which can be

opened and shut occasionally.

The boiler is filled about half full of water, and a strong fire is placed under it: then, if the communication between the boiler and the cylinder be opened, the cylinder will be filled with hot steam; which would drive the piston quite out at the top of it. But there is a contrivance by which the beam, when the piston is near the top of the cylinder, shuts the communication at the top of the boiler within.

This

This is no fooner shut, than another is opened, by which a little cold water is thrown upward in a jet into the cylinder, which mixing with the hot steam, condenses it immediately; by which means a vacuum is made in the cylinder, and the piston is pressed down by the weight of the atmosphere; and so lists up the loaded pumprod at the other end of the beam.

If the cylinder be 42 inches in diameter, the pifton will be preffed down with a force greater than 20000 pounds, and will confequently lift up that weight at the opposite end of the beam: and as the pump-rod with its plunger is fixed to that end, if the bore where the plunger works were 10 inches diameter, the water would be forced up through a pipe of 180 yards perpendicular height.

But, as the parts of this engine have a good deal of friction, and must work with a considerable velocity, and there is no such thing as making a perfect vacuum in the cylinder, it is found that no more than 8 pounds of pressure must be allowed for, on every circular inch of the piston in the cylinder, that it may make about 16 strokes in a minute, about 6 feet each.

Where the boiler is very large, the piston will make between 20 and 25 strokes in a minute, and each stroke 7 or 8 feet; which, in a pump of 9 inches bore, will raise upward of 300 hogsheads of water in an hour.

It is found by experience that a cylinder, 40 inches diameter, will work a pump 10 inches diameter, and 100 yards long: and hence we can find the diameter and length of a pump, that can be worked by any other cylinder.

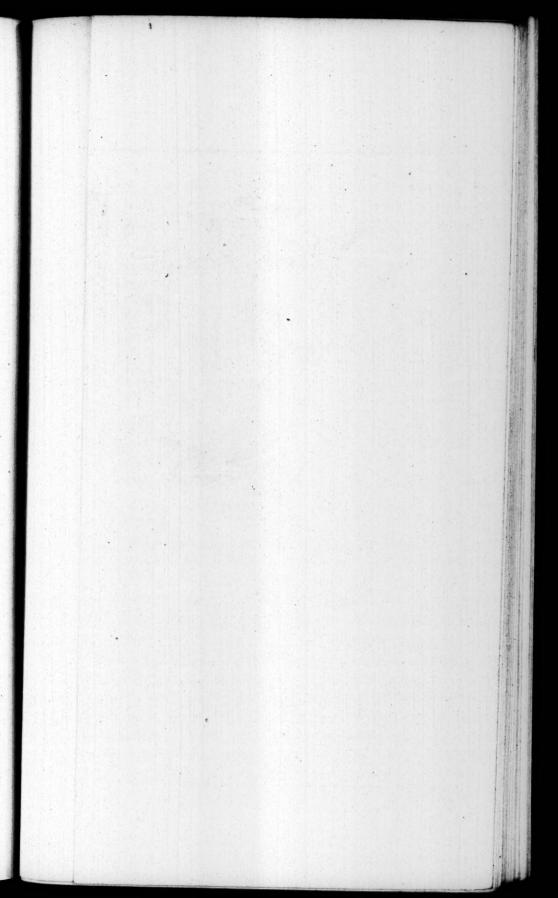
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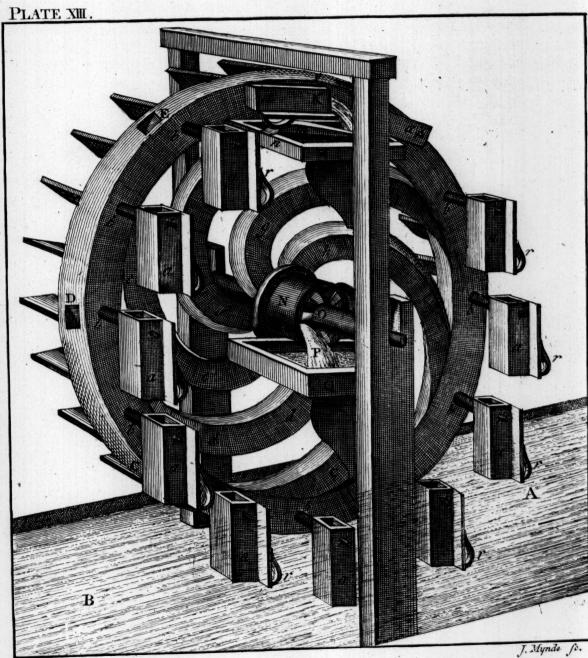
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For the convenience of those who would make use of this engine for raising water, we shall subjoin part of a table calculated by Mr. Beighton, shewing how any given quantity of water may be raised in an hour, from 48 to 400 hogsheads; at any given depth, from 15 to 100 yards; the machine working at the rate of 16 strokes per minute, and each stroke being 6 feet

long.

One example of the use of this table will make the whole plain. Suppose it were required to draw 100 hogsheads per hour, at 90 yards depth: in the second column from the right hand, I find the nearest number, viz. 149 hogsheads 40 gallons, against which, on the right hand, I find the diameter of the bore of the pump must be 7 inches; and in the same collateral line, under the given depth 90, I find 27 inches, the diameter of the cylinder sit for that purpose.—And so for any other.





9. Ferguoon detin.

	This gallons,	tab at	le is calculated to the measure of ale 282 cubic inches per gallon.
	Diam. of pump.	Inches.	1 1 0 0 8 8 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6
fire.	nour.	Gal.	21 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
A Table shewing the power of the engine for raising water by fire.	In one hour.	Hogh.	946 9369 9369 1122 1128 1128 1128 1128 128 149 149 149 149 149 149 149 149
g wa		100	4 6 6 6 6 6 6 7 7 7 1 1 1 1 1 1 1 1 1 1 1
raifin		90	2 € € € € 8 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
for r	80	3.90 2.20 2.20 2.20 2.20 2.20 1.00 1.00 1.0	
engin		10	0 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
the o	rds.	99	66 62 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1
er of	ı in ya	50	10000000000000000000000000000000000000
powed	drawr	45	20142222211 1207748110008002811
the c	The depth to be drawn in yards.	40	0 % 1 % 2 % 2 % 1 1 1 1 1 1 1 1 1 1 1 1 1
ewing	depth	35	$\begin{array}{cccccccccccccccccccccccccccccccccccc$
le fb	The	30	2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
Tab		25	42021 42081 17001 14441
A		20	1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
		15	18 1 2 4 6 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
			Diameter of the cylinder in inches.

Plate XIII. The Perfian wheel.

Water may be raifed by means of a ffream AB turning a wheel CDE, according to the order of the letters, with buckets a, a, a, a, &c. hung upon the wheel by ftrong pins b, b, b, b, &c. fixed in the fide of the rim: but the wheel must be made as high as the water is intended to be raifed above the level of that part of the stream in which the wheel is placed. As the wheel turns, the buckets on the right-hand go down into the water, and are filled therewith, and go up full on the left hand, until they come to the top at K; where they strike against the end n of the fixed trough M, and are thereby overfet, and empty the water into the trough; from which it may be conveyed in pipes to the place which it is defigned for: and as each bucket gets over the trough, it falls into a perpendicular position again, and goes down empty, until it comes to the water at A, where it is filled as before. On each bucket is a fpring r, which goes over the top or crown of the bar m (fixed to the trough M) raises the bottom of the bucket above the level of its mouth, and fo causes it to empty all its water into the trough.

Sometimes this wheel is made to raise water no higher than its axle; and then, instead of buckets hung upon it, its spokes C, d, e, f, g, h, are made of a bent form, and hollow within; these hollows opening into the holes C, D, E, F, in the outside of the wheel, and also into those at O in the box N upon the axle. So that, as the holes C, D, &c. dip into the water, it runs into them; and as the wheel turns, the water rises in the hollow spokes, c, d, &c. and runs out in a stream P from the holes at O, and falls into the trough  $\mathcal{Q}$ , from whence it is conveyed by pipes. And this is a very easy way of raising

water,

water, because the engine requires no animal power to turn it.

The art of weighing different bodies in water, Of the and thereby finding their specific gravities, or specific weights, bulk for bulk, was invented by Ar-gravities of bodies. CHIMEDES; of which we have the following account:

Hiero, king of Syracuse, having employed a goldsmith to make a crown, and given him a mass of pure gold for that purpose, suspected that the workman had kept back part of the gold for his own use, and made up the weight by allaying the crown with copper. But the king, not knowing how to find out the truth of that matter, referred it to Archimedes; who having studied a long time in vain, found it out at last by chance. For, going into a bathingtub of water, and observing that he thereby raised the water higher in the tub than it was before, he concluded instantly that he had raised it just as high as any thing else could have done, that was exactly of his bulk: and confidering that any other body of equal weight, and of less bulk than himself, could not have raised the water fo high as he did; he immediately told the king, that he had found a method by which he could discover whether there were any cheat in the crown. For, fince gold is the heaviest of all known metals, it must be of less bulk, according to its weight, than any other metal. And therefore he defired that a mass of pure gold, equally heavy with the crown when weighed in air, should be weighed against it in water; and if the crown was not allayed, it would counterpoise the mass of gold when they were both immerfed in water, as well as it did when they were weighed in air. But upon L4 making

making the trial, he found that the mass of gold weighed much heavier in water than the crown And not only fo, but that, when the mass and crown were immerfed feparately in one veffel of water, the crown raifed the water much higher than the mass did; which shewed it to be allayed with fome lighter metal that increased its bulk. And fo, by making trials with different metals, all equally heavy with the crown when weighed in air, he found out the quantity of alloy in the crown.

The specific gravities of bodies are as their weights, bulk for bulk; thus a body is faid to have two or three times the specific gravity of another, when it contains two or three times as

much matter in the fame space.

A body immerfed in a fluid will fink to the bottom, if it be heavier than its bulk of the fluid. If it be fuspended therein, it will lose as much of what it weighed in air, as its bulk of the fluid weighs. Hence, all bodies of equal bulks, which would fink in fluids, lofe equal weights when fuspended therein. And unequal bodies lose in proportion to their bulks.

The hydrostatic balance.

The hydrostatic balance differs very little from a common balance that is nicely made: only it has a hook at the bottom of each scale, on which fmall weights may be hung by horfehairs, or by filk threads. So that a body, fufpended by the hair or thread, may be immerfed in water without wetting the scale from which it hangs.

How to find the **f**pecific

If the body thus suspended under the scale, at one end of the balance, be first counterpoised gravity of in air by weights in the opposite scale, and then any body. immerfed into water, the equilibrium will be immediately destroyed. Then, if as much weight

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be put into the scale from which the body hangs, as will restore the equilibrium (without altering the weights in the opposite scale) that weight, which restores the equilibrium, will be equal to the weight of a quantity of water as big as the immerfed body. And if the weight of the body in air be divided by what it loses in water, the quotient will shew how much that body is heavier than its bulk of water. Thus, if a guinea suspended in air, be counterbalanced by 129 grains in the opposite scale of the balance; and then, upon its being immersed in water, it becomes fo much lighter, as to require 71 grains put into the scale over it, to restore the equilibrium, it shews that a quantity of water, of equal bulk with the guinea, weighs 74 grains, or 7.25; by which divide 129 (the weight of the guinea in air) and the quotient will be 17.793; which shews that the guinea is 17.793 times as heavy as its bulk of water. And thus, any piece of gold may be tried, by weighing it first in air, and then in water; and if upon dividing the weight in air by the loss in water, the quotient comes out to be 17.793, the gold is good; if the quotient be 18, or between 18 and 19, the gold is very fine; but if it be less than 17, the gold is too much allayed, by being mixed with fome other metal.

If filver be tried in this manner, and found to be 11 times as heavy as water, it is very fine; if it be  $10\frac{1}{2}$  times as heavy, it is ftandard; but if it be of any less weight compared with water, it is mixed with some lighter metal, such as tin.

By this method, the specific gravities of all bodies that will fink in water, may be found. But as to those which are lighter than water, as most

most forts of wood are, the following method may be taken, to shew how much lighter they

are than their respective bulks of water.

Let an upright flud be fixed into a thick flat piece of brass, and in this stud let a small lever, whose arms are equally long, turn upon a fine pin as an axis. Let the thread which hangs from the scale of the balance be tied to one end of the lever, and a thread from the body to be weighed, tied to the other end. This done, put the brass and lever into a vessel, then pour water into the vessel, and the body will rife and float upon it, and draw down the end of the balance from which it hangs; then, put as much weight in the opposite scale as will raise that end of the balance, fo as to pull the body down into the water by means of the lever; and this weight in the scale will shew how much the body is lighter than its bulk of water.

There are fome things which cannot be weighed in this manner, fuch as quickfilver, fragments of diamonds, &c. because they cannot be suspended in threads; and must therefore be put into a glass bucket, hanging by a thread from the hook of one scale, and counterpoised by weights put into the opposite scale. suppose you want to know the specific gravity of quickfilver, with respect to that of water; let the empty bucket be first counterpoised in air, and then the quickfilver put into it and weighed. Write down the weight of the bucket, and also of the quickfilver; which done, empty the bucket, and let it be immersed in water as it hangs by the thread, and counterpoifed therein by weights in the opposite scale: then, pour the quickfilver into the bucket in the water, which will cause it to preponderate; and put as

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much weight into the opposite scale as will reflore the balance to an equiposite; and this weight will be the weight of a quantity of water equal in bulk to the quickfilver. Lastly, divide the weight of the quickfilver in air, by the weight of its bulk of water, and the quotient will shew how much the quickfilver is heavier than its bulk of water.

If a piece of brass, glass, lead, or filver, be immersed and suspended in different forts of sluids, the different losses of weight therein will shew how much it is heavier than its bulk of the fluid; the fluid being lightest in which the immersed body loses least of its aerial weight. A solid bubble of glass is generally used for finding the specific gravities of fluids.

Hence we have an easy method of finding the specific gravities both of solids and fluids, with regard to their specific bulks of common pump water, which is generally made a standard for

comparing all others by.

In conftructing tables of specific gravities with accuracy, the gravity of water must be reprefented by unity or 1.000, where three cyphers are added, to give room for expressing the ratios of other gravities in decimal parts, as in the following table.

N. B. Although guinea gold has been generally reckoned 17.798 times as heavy as its bulk of water, yet, by many repeated trials, I cannot fay that I have found it to be more than 17.200

(or  $17\frac{2}{10}$ ) as heavy.

# Of the specific Gravities of Bodies.

# A Table of the specific gravities of several folid and fluid bodies.

A cubic inch of	Tı	oy v	veight.	Av	oirdup.	Compa-
A cubic inch of	oz.	Pv	v. gr.	oz.	drams.	rative weight.
Very fine gold -	10	7	3.83	11	5.80	19.637
Standard gold -	9	19	6.44	10	14.90	18.888
Guinea gold -	9	7	17.18	10	4.76	17.793
Moidore gold -	9	0	19.84	9	14.71	17.140
Quickfilver -	7	7	11.61	8	1.45	14.019
Lead	5	19	17.55	6	9.08	11.325
Fine filver	5	16	23.23	6	6.66	11.087
Standard filver -	5	11	3.36	6	1.54	10.535
Copper	4	13		5	1.89	8.843
Plate brafs	4	4	9.60	4	10.09	8.000
Steel	4	2	20.12	4	8.70	7.852
Iron	4	0	15.20	4	6.77	7.645
Blocktin	3	17	5.68	4	3.79	7.321
Speltar	3	14	12.86	4	1.42	7.065
Lead ore	3	11	17.76	3	14.96	6.800
Glass of antimony	2	15	16.89	3	0.89	5.280
Germanantimony	2	2	4.80	2	5.04	4.000
Copper ore	2	1	11.83	2	4.43	3.775
Diamond	1	15	20.88	1	15.48	3.400
Clear glass	I	13	5.58	I	13.16	3.150
Lapis lazuli -	1	12	5.27	1	12.27	3.054
Welch asbestos -	I	10	17.57	1	10.97	2.913
White marble -	I	8	13.41	1	9.06	2.707
Black ditto	1	8	12.65	I	9.02	2.704
Rock c ystal -	I	8	1.00	I	8.61	2.658
Greer glass -	I	7	15.38	I	8.26	2 620
Cornelian stone	1	7	1.21	1	7.73	2 568
Flint	I	6	19.63	1	7.53	2.542
Hard paving stone	1	5	22.87	1	6.77	2.460
Live fulphur -	I	1	2.40	1	2.52	2.000
Nitre	I	0	1.08	1	1.59	1.900
Alabaster	0	19	18.74	1	1.35	1.875
Dry ivory	0	19	6.09	I	0.89	1.825
Brimstone	0	18	23.76	I	0.66	1.800
Alum	0	17	21.92	0	15.72	1.714

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The Table concluded.

A cubic inch of	Tr	oy v	weight.	Av	oirdup.	Compa-	
A cubic inch of	oz.	pv	v. gr	oz.	drams.	rative weight.	
Ebony	0	11	18.82	0	10.3		
Human blood -	0	11	2.89	0	9.70	1.054	
Amber	0	10	20.79	0	9.54	1.030	
Cow's milk -	0	10	20.79	0	9.54	1.030	
Sea water	-0	10	20.79	0	9.54	1.030	
Pump water -	0	10	13.30	0	9.26	1.000	
Spring water -	0	10	12.94	0	9.25	0.999	
Distilled water -	0	10	11.42	0	9.20	0.993	
Red wine	0	10	11.42	0	9.20	0.993	
Oil of amber -	0	10	7.63	0	9.06	0.978	
Proof spirits -	0	9	19.73	0	8.62	0.931	
Dry oak	0	9	18.00	0	8.56	0.925	
Olive oil	0	9	15.17	0	8.45	0.913	
Pure spirits	0	9	3.27	0	8.02	0.866	
Spirit of turpentine	0	8	2.76		7.99	0.864	
Oil of turpentine	0		8.53	0	7.33	0.772	
Dry crabtree -	0	8	1.69	0	7.08	0.765	
Saffafras wood -	0	5	2.04	0	4.46	0.482	
Cork	0	2	12.77	0	2.21	0.240	

Take away the decimal points from the numbers in the right-hand column, or (which is the fame) multiply them by 1000, and they will shew low many avoirdupoife ounces are contained in a cubic foot of each body.

The use of the table of specific gravities will How to best appear by an example. Suppose a body to find out be compounded of gold and filver, and it is re-tity of quired to find the quantity of each metal in the adulteracompound.

First find the specific gravity of the com- metals. pound, by weighing it in air and in water, and dividing its aerial weight by what it loses thereof in water, the quotient will shew its specific gravity,

tion in

gravity, or how many times it is heavier than its bulk of water. Then, subtract the specific gravity of filver (found in the table) from that of the compound, and the specific gravity of the compound from that of gold; the first remainder shews : bulk of gold, and the latter the bulk of filver, in the whole compound: and if these remainders be multiplied by the respective specific gravities, the products will shew the proportion of weights of each metal in the body.

Example.

Suppose the specific gravity of the compounded body be 13; that of standard silver (by the table) is 10.5, and that of gold 19.63: therefore 10.5 from 13, remains 2.5, the proportional bulk of the gold; and 13 from 19.63, remains 6.63 the proportional bulk of filver in the compound. Then, the first remainder 2.5, multiplied by 19.63, the specific gravity of gold, produces 49.075 for the proportional weight of gold; and the last remainder 6.63 multiplied by 10.5, the specific gravity of silver, produces 69.615 for the proportional weight of filver in the whole body. So that for every 49.07 ounces or pounds of gold, there are 69.6 pounds or ounces of filver in the body.

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Hence it is easy to know whether any suspected metal be genuine, or allayed, or counterfeit; by finding how much it is heavier than its bulk of water, and comparing the fame with the table: if they agree, the metal is good; if they

differ, it is allayed or counterfeited.

A cubical inch of good brandy, rum, or other proof spirits, weighs 235.7 grains: therefore, if a true inch cube of any metal weighs 235.7 grains less in spirits than in air, it shews the fpirits are proof. If it loses less of its aerial weight

How to try fpirituous liquors.

weight in spirits, they are above proof; if it loses more, they are under. For, the better the fpirits are, they are the lighter; and the worfe, the heavier. All bodies expand with heat, and contract with cold, but some more and some less than others. And therefore the specific gravities of bodies are not precifely the fame in fummer as in winter. It has been found, that a cubic inch of good brandy is ten grains heavier in winter than in fummer; as much spirit of nitre, 20 grains; vinegar 6 grains, and fpring-water 3. Hence it is most profitable to buy spirits in winter, and fell them in fummer, fince they are always bought and fold by measure. It has been found, that 32 gallons of spirits in winter will make 33 in fummer.

The expansion of all fluids is proportionable to the degree of heat; that is, with a double or triple heat a fluid will expand two or three times

as much.

Upon these principles depend the construction of the thermometer, in which the globe or mometer. bulb, and part of the tube, are filled with a shuid, which, when joined to the barometer, is spirits of wine tinged, that it may be more easily seen in the tube. But when thermometers are made by themselves, quicksilver is generally used.

In the thermometer, a scale is sitted to the tube, to shew the expansion of the quicksilver, and consequently the degree of heat. And, as Fabrenheit's scale is most in esteem at present, I shall explain the construction and graduation of thermometers according to that scale.

First, let the globe or bulb, and part of the tube, be filled with a fluid; then immerse the bulb in water just freezing, or snow just thaw-

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ing; and even with that part in the scale where the fluid then stands in the tube, place the number 32, to denote the freezing point: then put the bulb under your arm-pit, when your body is of a moderate degree of heat, so that it may acquire the same degree of heat with your skin; and when the sluid has risen as far as it can by that heat, there place the number 97: then divide the space between these numbers into 65 equal parts, and continue those divisions both above 97 and below 32, and number them accordingly.

This may be done in any part of the world; for it is found that the freezing point is always the fame in all places, and the heat of the human body differs but very little; fo that the thermometers made in this manner will agree with one another; and the heat of feveral bodies will be fhewn by them, and expressed by the numbers

upon the scale, thus:

Air, in fevere cold weather, in our climate, from 15 to 25. Air in winter, from 26 to 42. Air in fpring and autumn, from 43 to 53. Air at midfummer, from 65 to 68. Extreme heat of the fummer fun, from 86 to 100. Butter just melting, 95. Alcohol boils with 174 or 175. Brandy with 190. Water 212. Oil of turpentine 550. Tin melts with 408, and lead with 540. Milk freezes about 30, vinegar 38, and blood 27.

A body specifically lighter than a fluid will fwim upon its surface, in such a manner, that a quantity of the fluid, equal in bulk with the immersed part of the body, will be as heavy as the whole body. Hence, the lighter a fluid is, the deeper a body will sink in it; upon which

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depends the construction of the bydrometer or

water-poife.

From this we can easily find the weight of a How the ship, or any other body that floats in water. weight of For, if we multiply the number of cubic feet a ship which are under the surface, by 62.5, the number of pounds in one cubic foot of fresh water; or by 64.4, the number of pounds in a cubic foot of salt water; the product will be the weight of the ship, and all that is in it. For, since it is the weight of the ship that displaces the water, it must continue to sink until it has removed as much water as is equal to it in weight; and therefore the part immersed must be equal in bulk to such a portion of the water as is equal to the weight of the whole ship.

To prove this by experiment, let a ball of fome light wood, such as fir or pear-tree, be put into water contained in a glass vessel; and let the vessel be put into a scale at one end of a balance, and counterpoised by weights in the opposite scale: then, marking the height of the water in the vessel, take out the ball; and fill up the vessel with water to the same height that it stood at when the ball was in it; and the same weight

will counterpoise it as before.

From the vessel's being filled up to the same height at which the water stood when the ball was in it, it is evident that the quantity poured in is equal in magnitude to the immersed part of the ball: and from the same weight counterpositing, it is plain that the water poured in, is equal in weight to the whole ball.

In troy weight, 24 grains make a pennyweight, 20 pennyweights make an ounce, and 12 ounces a pound. In avoirdupoise weight, 16 drams make an ounce, and 16 ounces a

pound.

pound. The troy pound contains 5760 grains, and the avoirdupoise pound 7000; and hence, the avoirdupoise dram weighs 27.34375 grains,

and the avoirdupoife ounce 437.5.

Because it is often of use to know how much any given quantity of goods in troy weight do make in avoirdupoise weight; and the reverse; we shall here annex two tables for converting these weights into one another. Those from page 135 to page 146 are near enough for common hydraulic purposes; but the two following are better, where accuracy is required in comparing the weights with one another: and I find, by trial, that 175 troy ounces are precifely equal to 192 avoirdupoise ounces, and 175 troy pounds are equal to 144 avoirdupoife. And although there are feveral leffer integral numbers, which come very near to agree together, yet I have found none less than the above to agree exactly. Indeed 41 troy ounces are fo nearly equal to 45 avoirdupoise ounces, that the latter contains only 71 grains more than the former: and 45 troy pounds weigh only 7 3 drams more than 37 avoirdupoife.

I have lately made a scale for comparing these weights with one another, and shewing the weight of pump-water, proof spirits, pure spirits, and guinea gold, taken in cubic inches, to any quantity less than a pound, both in troy and avoirdupoise; only by sliding one side of a square along

the scale, and the other side crossing it.

T	Troy Weight.	Avo	oirdu	poise.	Troy Weight.	Avoir.
	Troy weight.	lb.	oz.	drams.	Troy weight.	Drams.
	Pounds—4000	3291	6	13.68	Pennywt. 19	16.67
	3000	2528	9	2.26	18	
	2000	1645	11	6.84	17	14.92
1.:	1000	822		11.42	16	14.04
A Table for reducing Troy weight into Avoirdupoife weight.	900	740	9	2.28	15	13.16
1.5	800	658	4	9.14	14	12.29
3	700	576		0.00	13	11.41
le l	600	493	II	6.85	12	10.53
0	500	411	6	13.71	11	9.65
dr	400	329	2	4.57	10	8.78
d.	300	246	13	11.42	9	7.90
1.2	200	164	9	2.28		7.02
1	100	82	4	9.15	7 6	6.14
A	90 80	74	0	13.62		5.27
13	50	65	13	9.60	5	4.39
1.5	70 60	57	9	15.08	5 4 3	2.63
1	50	49	5 2	4.57	2	1.75
00	40	32	14	10.05	1	1.75
vei	30	24	10	15.54	Grains - 23	.84
>	20	16	7	5.03	22	.80
0	10	8	3	10.52	21	•77
1			6	7.86	20	•77 •73 •69
20	9 8	7 6	9	5.21	19	.69
136	7	5	12	2.56	18	.00
C.	7 6	4	14	15.90	17	.62
de	5	4	1	13.25	16	•58 •55
re	4	3	4	10.60	15	.55
15	5 4 3 2	2	7	7.95	14	.51
fe		I	10	5.30	13	•47
15	1		13	2.65	12	•44
वि	Ounces — 11		12	1.09	11	•40
H	10		10	15.54	10	-36
1	9		9	13.99	9	•33
	8		8	12.43		.20
	7		7	10.88	7 6	.26
	0		0	9.32	0	.18
	5		5	7.77	5	1.0
	4		4	6.22	4	.15
	3		3		3	-07
	2					.04
	9 8 7 6 5 4 3 2		3 2 1	4.66 3.11 1.55	5 4 3 2	.07

Avoird	upoife	Tro	y w	eigl	nt.	Avoir		Tro	y w	eight.
weight.		lb.	oz.	pw.	gr.	weigh	ıt.	lb. o	z. J	w. g
Pounds		7291	8	0	C	Ounces	15	1 1	13	10.5
		6076	4	13	8		14	1 0	15	5
	4000		I	6	16		13	11	16	23.5
	3000	3645	10	0	0		12	10	18	18
	2000		6	13	8		11	10	0	12.5
	1000	1215	3	6	16		10	9	2	7
	900	1093	9	0	0		9	8	4	1.5
	800	972	2	13	8		9	7 6	5	20
	700	850	8	6	15		7	6	7	14.5
	600	729	2	0	0			5	9	9
	500	607	7	13	8		5	4	11	3.5
	400	486	I	6	16		4	3	12	22
	300	364	7	0	0		3 2	2	14	16.50
	300	243	0	13	8			1	16	II
	100	121	6	6	16		1		18	5.50
	90	109	4	10		Drams	15		37	2.10
	80	97	2	13	8		14		15	22.76
	70	85	0	16	16		13		14	19.42
	60	72	II	0	0		12		13	15.08
	50	60	9	3	8		11		12	12.74
	40	48	7		16		10		11	9.40
	30	36	5	10	0		9		10	6.06
	10	24		13	8 16				9	2.72
		12	II		- 1		7		8	23.38
	9			5	8				7	20.04
		9	6	13	16		5		6	16.70
	7 6			10	0		4		5	13.36
	5	76		18	8		3 2		3 2	6,68
	4		10		16		1		1	
	3	3		15	0					3.34
	3	2	5	3	8		ज्यातम् ।			20.51
	1	1		11	16		1			6.83

The two following examples will be fufficient to explain these two tables, and shew their agreement.

Ex. I. In 6835 pounds 6 ounces 9 pennyweights 6 grains Troy, Qu. How much Avoirdupoise weight? (See page 165.)

		Avoirdu	poise.
		lb. oz. d	lrams.
	T4000	3291 6	13.68
	2000	1645 11	6.84
Pounds	800	658 4	9.14
troy-	20	16 7	5.03
	10	8 3	10.52
	z. 6	4 I	13.25
0	z. 6	6	9.32
P	w. 9		7.90
٤	gr. 6		.22

Answer. | 5624 10 11.90

Ex. II. In 5624 pounds 10 ounces 12 drams Avoirdupoise, Qu. How much Troy weight? (See page 166.)

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#### LECT. VI.

## Of Pneumatics.

THIS science treats of the nature, weight, preffure, and fpring of the air, and the

effects arising therefrom.

The proair.

The air is that thin transparent fluid body in perties of which we live and breathe. It encompasses the whole earth to a confiderable height; and, together with the clouds and vapours that float therein, it is called the atmosphere. The air is justly reckoned among the number of fluids, because it has all the properties by which a fluid is diftinguished. For, it yields to the least force impressed, its parts are easily moved among one another, it presses according to its perpendicular height, and its pressure is every way equal.

That the air is a fluid, confifting of fuch particles as have no cohesion between them, but eafily glide over one another, and yield to the flightest impression, appears from that ease and freedom with which animals breathe in it, and move through it without any difficulty or fensible

refiftance.

But it differs from all other fluids in the four following particulars: 1. It can be compressed into a much lefs space than what it naturally possesses, which no other fluid can. 2. It cannot be congealed or fixed, as other fluids may. is of a different density in every part, upward from the earth's furface, decreasing in its weight, bulk for bulk, the higher it rifes; and therefore must also decrease in density. 4. It is of an elastic

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elastic or springy nature, and the force of its

fpring is equal to its weight.

That air is a body, is evident from its excluding all other bodies out of the space it possesses for, if a glass jar be plunged with its mouth downward into a vessel of water, there will but very little water get into the jar, because the air of

which it is full keeps the water out.

As air is a body, it must needs have gravity or weight: and that it is weighty, is demonstrated by experiment. For, let the air be taken out of a vessel by means of the air-pump, then, having weighed the vessel, let in the air again, and upon weighing it when re-filled with air, it will be found considerably heavier. Thus, a bottle that holds a wine quart, being emptied of air and weighed, is found to be about 16 grains lighter than when the air is let into it again; which shews that a quart of air weighs 16 grains. But a quart of water weighs 14621 grains; this divided by 16, quotes 914 in round numbers; which shews, that water is 914 times as heavy as air near the surface of the earth.

As the air rifes above the earth's furface, it grows rarer, and confequently lighter, bulk for bulk. For, because it is of an elastic or springy nature, and its lowermost parts are pressed with the weight of all that is above them, it is plain that the air must be more dense or compact at the earth's surface, than at any height above it; and gradually rarer the higher up. For, the density of the air is always as the force that compresses it; and therefore, the air toward the upper parts of the atmosphere being less pressed than that which is near the earth, it will expand itself, and thereby become thinner than at the earth's surface.

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Dr. Cotes has demonstrated, that if altitudes in the air be taken in arithmetical proportion, the rarity of the air will be in geometrical proportion. For instance,

77		1-	-	-	-	-	-	-	-		4
14	. 15	-	-	-	-	-	-	-	-		16
21	aii	-	-	-	-	-	-	-	-		64
28	the air	-	-	-	-	-	-	-		2	56
35 42	1	-	-	-	-	-	-	•			24
42	th	-	-	-	-	-	-	-		40	96
49	ear	-	-	-	-	-	-		I	63	84
56	the earth,	-	•	-	-	-	-		6	55	36
63	=	-	-	-	-	-		:	26	21	44
63	10	) -	-	-	-	-		10	04	85	76
77	3	1 -	-	-	-	-		4	19	43	304
84	rfa	-	-	-	-						116
91	5	1-	-	-	-		6	7	10	88	864
98	he	1-	-	-	-						156
105	e	-	-	-		1	07	3	74	18	324
112	00	1 -	-	-							296
119	l de	-	-	-		17	17	19	36	91	84
126	ies	-	-			68	71	19	47	67	36
133	miles above the furface of	-	-								144
140-	) -	L		1	10	99	5	11	62	77	776.

And hence it is easy to prove by calculation, that a cubic inch of fuch air as we breathe, would be fo much rarefied at the altitude of 500 miles, that it would fill a hollow fphere equal in diameter to the orbit of Saturn.

The weight or pressure of the air is exactly determined by the following experiment:

The Toricellian experiment.

Take a glass tube about three feet long, and open at one end; fill it with quickfilver, and putting your finger upon the open end, turn that end downward, and immerfe it into a small veffel

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vessel of quicksilver, without letting in any air: then take away your finger; and the quickfilver will remain suspended in the tube 29½ inches above its furface in the vessel; sometimes more, and at other times less, as the weight of the air is varied by winds and other causes. the quickfilver is kept up in the tube by the pressure of the atmosphere upon that in the bason, is evident; for, if the bason and tube be put under a glass, and the air be then taken out of the glass, all the quicksilver in the tube will fall down into the bason; and if the air be let in again, the quickfilver will rife to the fame height as before. Therefore the air's pressure on the furface of the earth, is equal to the weight of 29½ inches depth of quickfilver all over the earth's furface, at a mean rate.

A square column of quicksilver, 292 inches high, and one inch thick, weighs just 15 pounds, which is equal to the pressure of air upon every square inch of the earth's surface; and 144 times as much, or 2160 pounds, upon every iquare foot; because a square foot contains 144 square inches. At this rate, a middlefized man, whose furface may be about 14 square feet, fustains a pressure of 30240 pounds, when the air is of a mean gravity: a pressure which would be insupportable, and even fatal to us, were it not equal on every part, and counterbalanced by the fpring of the air within us, which is diffused through the whole body; and reacts with an equal force against the outward preffure.

Now, fince the earth's furface contains (in round numbers) 200,000,000 fquare miles, and every fquare mile 27,878,400 fquare feet, there must be 5,575,680,000,000,000 fquare

feet on the earth's furface; which multiplied by 2160 pounds (the pressure on each square foot) gives 12,043,468,800,000,000 pounds for the pressure or weight of the whole atmos-

phere.

When the end of a pipe is immerfed in water, and the air is taken out of the pipe, the water will rife in it to the height of 33 feet above the furface of the water in which it is immerfed; but will go no higher; for it is found, that a common pump will draw water no higher than 33 feet above the furface of the well: and unless the bucket goes within that distance from the well, the water will never get above it. Now, as it is the pressure of the atmosphere, on the furface of the water in the well, that causes the water to ascend in the pump, and follow the piston or bucket, when the air above it is lifted up; it is evident, that a column of water 33 feet high, is equal in weight to a column of quickfilver of the same diameter, 291 inches high; and to as thick a column of air, reaching from the earth's furface to the top of the atmosphere.

The barometer.

In ferene calm weather, the air has weight enough to support a column of quickfilver 31 inches high; but in tempestuous stormy weather, not above 28 inches. The quickfilver, thus supported in a glass tube, is found to be a nice counterbalance to the weight or preffure of the air, and to shew its alterations at different times. And being now generally used to denote the changes in the weight of the air, and of the weather confequent upon them, it is called the barometer, or weather-glass.

The pressure of the air being equal on all fides of a body exposed to it, the fostest bodies

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fustain this pressure without suffering any change in their figure; and so do the most brittle bodies without being broke.

The air is rarefied, or made to swell with heat; and of this property, wind is a necessary conse. The cause quence. For, when any part of the air is heated of avinds, by the sun, or otherwise, it will swell, and thereby affect the adjacent air: and so, by various degrees of heat in different places, there will arise various winds.

When the air is much heated, it will ascend toward the upper part of the atmosphere, and the adjacent air will rush in to supply its place; and therefore, there will be a stream or current of air from all parts toward the place where the heat is. And hence we see the reason why the air rushes with such sorce into a glass-house, or toward any place where a great fire is made. And also, why smoke is carried up a chimney, and why the air rushes in at the key-hole of the door, or any small chink, when there is a fire in the room. So we may take it in general, that the air will press toward that part of the world where it is most heated.

Upon this principle, we can easily account for The treate-the trade-winds, which blow constantly from east winds. to west about the equator. For, when the sun shines perpendicularly on any part of the earth, it will heat the air very much in that part, which air will therefore rise upward, and when the sun withdraws, the adjacent air will rush in to fill its place; and consequently will cause a stream or current of air from all parts toward that which is most heated by the sun. But as the sun, with respect to the earth, moves from east to west, the common course of the air will be that way too; continually pressing after the sun: and therefore,

therefore, at the equator, where the fun fhines ftrongly, there will be a continual wind from the east; but, on the north-side, it will incline a little to the north, and on the south-side, to the south.

This general course of the wind about the equator, is changed in feveral places, and upon feveral accounts; as, 1. By exhalations that rife out of the earth at certain times, and from certain places; in earthquakes, and from volcanoes. 2. By the falling of great quantities of rain, causing thereby a sudden condensation or contraction of the air. 3. By burning fands, that often retain the folar heat to a degree incredible to those who have not felt it, causing a more than ordinary rarefaction of the air contiguous to them. 4. By high mountains, which alter the direction of the winds in striking against 5. By the declination of the fun toward the north or fouth, heating the air on the north or fouth-fide of the equator.

The mon-

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To these and such like causes is owing, 1. The irregularity and uncertainty of winds in climates distant from the equator, as in most parts of 2. Those periodical winds, called Europe. monfoons, which in the Indian feas blow half a year one way, and the other half another. 3. Those winds which, on the coast of Guinea, and on the western coasts of America, blow always from west to east. 4. The sea-breezes, which, in hot countries, blow generally from fea to land, in the day-time; and the landbreezes, which blow in the night; and, in short, all those storms, hurricanes, whirlwinds, and irregularities, which happen at different times and places.

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All common air is impregnated with a cer-The vivitain kind of vivifying spirit or quality, which is sping spirit necessary to continue the lives of animals: and in air this, in a gallon of air, is sufficient for one man during the space of a minute, and not much

longer.

This fpirit in air is deftroyed by paffing through the lungs of animals: and hence it is, that an animal dies foon, after being put under a veffel which admits no fresh air to come to it. This spirit is also in the air which is in water; for fish die when they are excluded from fresh air, as in a pond that is closely frozen over. And the little eggs of insects, stopped up in a glass, do not produce their young, though assisted by a kindly warmth. The seed also of plants mixed with good earth, and inclosed in a glass, will not grow.

This enlivening quality in air, is also destroyed by the air's passing through fire; particularly charcoal fire, or the slame of sulphur. Hence, smoking chimneys must be very unwholesome, especially if the rooms they are in be small and

close.

Air is also vitiated, by remaining closely pent up in any place for a confiderable time; or perhaps, by being mixed with malignant steams and particles flowing from the neighbouring bodies: or lastly, by the corruption of the vivifying spirit; as in the holds of ships, in oil-cisterns, or wine-cellars, which have been shut for a considerable time. The air in any of them is sometimes so much vitiated, as to be immediate death to any animal that comes into it.

Air that has lost its vivifying spirit, is called damp, not only because it is filled with humid Damps, or moist vapours, but because it deadens sire,

extinguishes flame, and destroys life. The dreadful effects of damps are sufficiently known to such as work in mines.

If part of the vivifying spirit of air in any country begins to putrefy, the inhabitants of that country will be subject to an epidemical disease, which will continue until the putrefaction is over. And as the putrefying spirit occasions the disease, so if the diseased body contributes toward the putrefying of the air, then the disease will not only be epidemical, but pestilential and contagious.

The atmosphere is the common receptacle of all the effluvia or vapours arising from different bodies; of the steams and smoke of things burnt or melted; the fogs or vapours proceeding from damp watery places; and of the effluvia from sulphureous, nitrous, acid, and alkaline bodies. In short, whatever may be called volatile, rises in the air to greater or less heights, according to

its specific gravity.

Fermenta-

When the effluvia, which arife from acid and alkaline bodies, meet each other in the air, there will be a firong conflict or fermentation between them; which will fometimes be fo great, as to produce a fire; then if the effluvia be combustible, the fire will run from one part to another, just as the inflammable matter happens to lie.

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Any one may be convinced of this, by mixing an acid and an alkaline fluid together, as the fpirit of nitre and oil of cloves; upon the doing of which, a fudden ferment, with a fine flame, will arise; and if the ingredients be very pure and strong, there will be a sudden explosion.

Thunder Whoever confiders the effects of fermentaand light-tion, cannot be at a loss to account for the uing.

dreadful dreadful effects of thunder and lightning: for the effluvia of fulphureous and nitrous bodies, and others that may rife into the atmosphere, will ferment with each other, and take fire very often of themselves; sometimes by the affishance of the sun's heat.

If the inflammable matter be thin and light, it will rife to the upper part of the atmosphere, where it will flash without doing any harm: but if it be dense, it will lie near the surface of the earth, where taking fire, it will explode with a surprising force; and by its heat rarefy and drive away the air, kill men and cattle, split trees, walls, rocks, &c. and be accompanied with ter-

rible claps of thunder.

The heat of lightning appears to be quite different from that of other fires; for it has been known to run through wood, leather, cloth, &c. without hurting them, while it has broken and melted iron, fteel, filver, gold, and other hard bodies. Thus it has melted or burnt afunder a fword, without hurting the fcabbard; and money in a man's pocket, without hurting his cloaths: the reason of this seems to be, that the particles of that fire are so fine, as to pass through soft loose bodies without dissolving them; while they spend their whole force upon the hard ones.

It is remarkable, that knives and forks which have been struck with lightning have a very strong magnetical virtue for several years after; and I have heard that lightning striking upon the mariner's compass, will sometimes turn it round; and often make it stand the contrary way, the north-pole toward the south.

Much of the same kind with lightning, are Firethose explosions, called fulminating or fire-damps, damps.

which fometimes happen in mines; and are occasioned by sulphureous and nitrous, or rather oleaginous particles, rifing from the mine, and mixing with the air, where they will take fire by the lights which the workmen are obliged to make use of. The fire being kindled, will run from one part of the mine to another, like a train of gunpowder, as the combustible matter happens to lie. And as the elafticity of the air is increased by heat, that in the mine will consequently swell very much, and so, for want of room, will explode with a greater or less degree of force, according to the density of the combustible vapours. It is fometimes fo strong, as to blow up the mine; and at other times fo weak, that when it has taken fire at the flame of a candle, it is eafily blown out.

Air that will take fire at the flame of a candle may be produced thus: Having exhausted a receiver of the air-pump, let the air run into it through the slame of the oil of turpentine; then remove the cover of the receiver, and holding a candle to that air, it will take fire, and burn quicker or slower, according to the density of

the oleaginous vapour.

When fuch combustible matter, as is abovementioned, kindles in the bowels of the earth, where there is little or no vent, it produces earthquakes, and violent storms or hurricanes of wind when it breaks forth into the air.

An artificial earthquake may be made thuse Take 10 or 15 pounds of fulphur, and as much of the filings of iron, and knead them with common water into the confiftency of a paste: this being buried in the ground, will, in 8 or 10 hours time, burst out in slames, and cause the

Earthquakes.

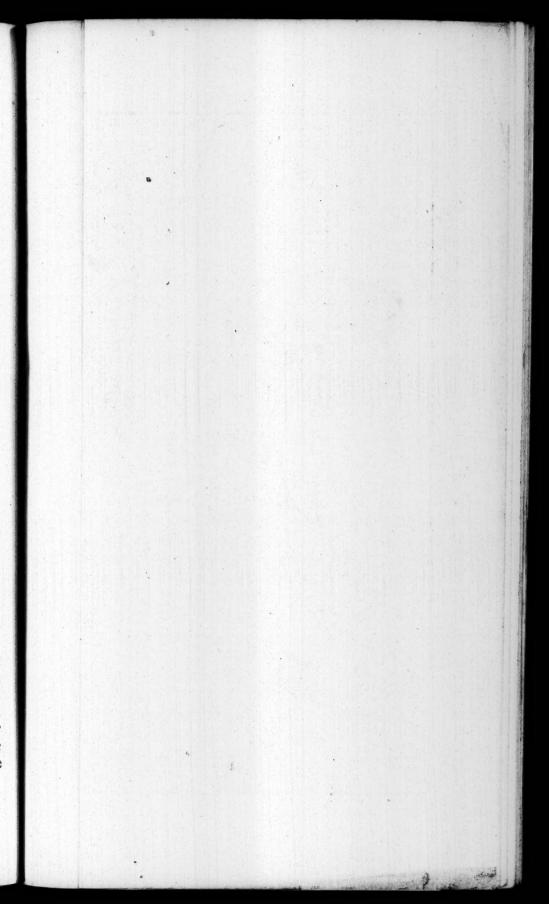
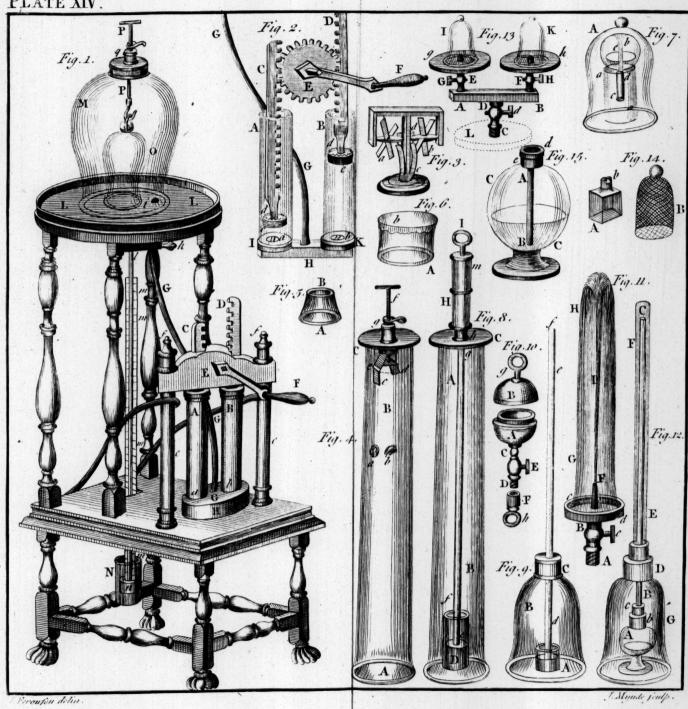


PLATE XIV.



the earth to tremble all around to a confiderable distance.

From this experiment we have a very natural account of the fires of mount Ætna, Vesuvius, and other volcanos, they being probably set on fire at first by the mixture of such metalline and sulphureous particles.

The air-pump being constructed the same way The airas the water-pump, whoever understands the one, pump.

will be at no loss to understand the other.

Having put a wet leather on the plate LL Plate of the air-pump, place the glass receiver M Fig. 1. upon the leather, fo that the hole i in the plate may be within the glass. Then, turning the handle F backward and forward, the air will be pumped out of the receiver; which will then be held down to the plate by the pressure of the external air, or atmosphere. For, as the handle F (Fig. 2.) is turned backward, it raises the pifton de in the barrel BK, by means of the wheel E and rack Dd: and, as the piston is leathered fo tight as to fit the barrel exactly, no air can get between the pifton and barrel; and therefore, all the air above d in the barrel is lifted up toward B, and a vacuum is made in the barrel from b to e; upon which, part of the air in the receiver M (Fig. 1.) by its spring, rushes through the hole i, in the brass plate LL, along the pipe GG, which communicates with both barrels by the hollow trunk IHK (Fig. 2.) and pushing up the valve b, enters into the vacant place be of the barrel BK. For, wherever the resistance or pressure is taken off, the air will run to that place, if it can find a paffage.—Then, if the handle F be turned forward, the piston de will be depressed in the barrel; and, as the air which had got into the barrel

barrel cannot be pushed back through the valve b, it will afcend through a hole in the pifton, and escape through a valve at d; and be hindered by that valve from returning into the barrel, when the piston is again raised. At the next raising of the piston, a vacuum is again made in the fame manner as before, between b and e; upon which, more of the air that was left in the receiver M, gets out thence by its fpring, and runs into the barrel BK, through The fame thing is to be underthe valve B. flood with regard to the other barrel A I; and as the handle F is turned backward and forward, it alternately raises and depresses the piftons in their barrels; always raising one while it depresses the other. And, as there is a vacuum made in each barrel when its piston is raised, the particles of air in the receiver M push out another by their spring or elasticity, through the hole i, and pipe GG into the barrels; until at last the air in the receiver comes to be fo much dilated, and its fpring fo far weakened, that it can no longer get through the valves; and then no more can be taken out. Hence, there is no fuch thing as making a perfect vacuum in the receiver; for the quantity of air taken out at any one stroke, will always be as the density thereof in the receiver: and therefore it is impossible to take it all out, because, fuppofing the receiver and barrels of equal capacity, there will be always as much left as was taken out at the last turn of the handle.

There is a cock k below the pump-plate, which being turned, lets the air into the receiver again; and then the receiver becomes loofe, and may be taken off the plate. The barrels are fixed to the frame E e e by two screw-nuts f f,

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which press down the top-piece E upon the barrels: and the hollow trunk H (in Fig. 2.) is co-

vered by a box, as GH in Fig. 1.

There is a glass tube lmmmn open at both ends, and about 34 inches long; the upper end communicating with the hole in the pump-plate, and the lower end immersed in quicksilver at n in the vessel N. To this tube is sitted a wooden ruler mm, called the gage, which is divided into inches and parts of an inch, from the bottom at n (where it is even with the surface of the quicksilver) and continued up to the top, a little below l, to 30 or 31 inches.

As the air is pumped out of the receiver M, it is likewise pumped out of the glass tube lmn, because that tube opens into the receiver through the pump-plate; and as the tube is gradually emptied of air, the quicksilver in the vessel N is forced up into the tube by the pressure of the atmosphere. And if the receiver could be perfectly exhausted of air, the quicksilver would stand as high in the tube as it does at that time in the barometer: for it is supported by the same power or weight of the atmosphere in both.

The quantity of air exhausted out of the receiver on each turn of the handle, is always proportionable to the ascent of the quicksilver on that turn; and the quantity of air remaining in the receiver, is proportionable to the defect of the height of the quicksilver in the gage, from

what it is at that time in the barometer.

I shall now give an account of the experiments made with the air-pump in my lectures; shewing the resistance, weight, and elasticity of the air.

### I. To shew the resistance of the air.

Fig. 3.

1. There is a little machine, confifting of two mills, a and b, which are of equal weights, independent of each other, and turn equally free on their axes in the frame. Each mill has four thin arms or fails, fixed into the axis: those of the mill a have their planes at right angles to its axis, and those of b have their planes parallel to Therefore, as the mill a turns round in common air, it is but little refisted thereby, because its fails cut the air with their thin edges: but the mill b is much refisted, because the broad fides of its fails move against the air when it turns round. In each axle is a pin near the middle of the frame, which goes quite through the axle, and stands out a little on each side of it: upon these pins the slider d may be made to bear, and fo hinder the mills from going, when the strong spring c is set on bend against the opposite ends of the pins.

Having fet this machine upon the pumpplate LL (Fig. 1.) draw up the flider d to the pins on one fide, and fet the spring c at bend upon the opposite ends of the pins: then push down the flider d, and the spring acting equally strong upon each mill, will fet them both a going with equal forces and velocities: but the mill a will run much longer than the mill b, because the air makes much less resistance against the edges of its fails, than against the sides of

the fails of b.

Draw up the flider again, and fet the fpring upon the pins as before; then cover the machine with the receiver M upon the pumpplate, and having exhaufted the receiver of air, pufh

Fig. 1.

push down the wire PP (through the collar of leathers in the neck q) upon the slider; which will disengage it from the pins, and above the mills to turn round by the impulse of the spring: and as there is no air in the receiver to make any sensible resistance against them, they will both move a considerable time longer than they did in the open air; and the moment that one stops, the other will do so too.—This shews that air resists bodies in motion, and that equal bodies meet with different degrees of resistance, according as they present greater or less surfaces to the air, in the planes of their motions.

2. Take off the receiver M, and the mills; Fig. 4. and having put the guinea a and feather b upon the brass flap c, turn up the flap, and shut it into the notch d. Then, putting a wet leather over the top of the tall receiver AB (it being open both at top and bottom) cover it with the plate C, from which the guinea and feather tongs e d will then hang within the receiver. This done, pump the air out of the receiver; and then draw up the wire f a little, which by a square piece on its lower end will open the tongs ed; and the flap falling down as at c, the guinea and feather will descend with equal velocities in the receiver; and both will fall upon the pump-plate at the fame instant.  $\cdot N$ . B. In this experiment, the obfervers ought not to look at the top, but at the bottom of the receiver; in order to fee the guinea and feather fall upon the plate; otherwise on account of the quickness of their motion, they will escape the fight of the beholders.

## II. To shew the weight of the air.

1. Having fitted a brass cap, with a valve tied over it, to the mouth of a thin bottle or Florence flask, whose contents are exactly known, fcrew the neck of this cap into the hole i of the pump-plate: then, having exhausted the air out of the flask, and taken it off from the pump, let it be fuspended at one end of a balance, and nicely counterpoifed by weights in the scale at the other end: this done, raise up the valve with a pin, and the air will rush into the flask with an audible noise: during which time, the flask will descend, and pull down that end of the beam. noise is over, put as many grains into the scale at the other end as will restore the equilibrium; and they will shew exactly the weight of the quantity of air which has got into the flask, and filled it. If the flask holds an exact quart, it will be found, that 16 grains will restore the equipoise of the balance, when the quickfilver stands at 29½ inches in the barometer: which shews, that when the air is at a mean rate of denfity, a quart of it weighs 16 grains: it weighs more when the quickfilver stands higher; and less when it stands lower.

2. Place the small receiver O (Fig. 1.) over the hole i in the pump-plate, and upon exhausting the air, the receiver will be fixed down to the plate by the pressure of the air on its outside, which is left to act alone, without any air in the receiver to act against it: and this pressure will be equal to as many times 15 pounds, as there are square inches in that part of the plate which the receiver covers; which will hold down the receiver so fast, that it cannot be got off, until

the air be let into it by turning the cock k; and then it becomes loofe.

3. Set the little glass AB (which is open at Fig. 5. both ends) over the hole i upon the pump-plate LL, and put your hand close upon the top of it at B: then, upon exhausting the air out of the glass, you will find your hand pressed down with a great weight upon it: so that you can hardly release it, until the air be re-admitted into the glass by turning the cock k; which air, by acting as strongly upward against the hand as the external air acted in pressing it downward, will release the hand from its confinement.

4. Having tied a piece of wet bladder b over Fig. 6. the open top of the glass A (which is also open at bottom) fet it to dry, and then the bladder will be tight like a drum. Then place the open end A upon the pump-plate, over the hole i, and begin to exhaust the air out of the glass. As the air is exhausting, its spring in the glass will be weakened, and give way to the pressure of the outward air on the bladder, which, as it is pressed down, will put on a sperical concave figure, which will grow deeper and deeper, until the strength of the bladder be overcome by the weight of the air; and then it will burst with a report as loud as that of a gun .- If a flat piece of glass be laid upon the open top of this receiver, and joined to it by a flat ring of wet leather between them; upon pumping the air out of the receiver, the pressure of the outward air upon the flat glass will break it to pieces.

5. Immerse the neck cd of the hollow glass Fig. 7. ball eb in water, contained in the phial aa; then set it upon the pump-plate, and cover it and the hole i with the close receiver A; and then begin

to pump out the air. As the air goes out of the receiver by its fpring, it will also by the fame means go out of the hollow ball eb, through the neck dc, and rife up in bubbles to the furface of the water in the phial; from whence it will make its way, with the rest of the air in the receiver. through the air-pipe GG and valves a and b, into the open air. When it has done bubbling in the phial, the ball is fufficiently exhaufted; and then, upon turning the cock k, the air will get into the receiver, and press so upon the surface of the water in the phial, as to force the water up into the ball in a jet, through the neck cd; and will fill the ball almost full of water. reason why the ball is not quite filled, is because all the air could not be taken out of it; and the fmall quantity that was left in, and had expanded itself fo as to fill the whole ball, is now condensed into the same state as the outward air, and remains in a small bubble at the top of the ball; and fo keeps the water from filling that part of the ball.

Fig. 8.

6. Pour some quicksilver into the jar D, and set it on the pump-plate near the hole i; then set on the tall open receiver AB, so as to be over the jar and hole; and cover the receiver with the brass plate C. Screw the open glass tube fg (which has a brass top on it at b) into the syringe H, and putting the tube through a hole in the middle of the plate, so as to immerse the lower end of the tube e in the quicksilver at D, screw the end b of the syringe into the plate. This done, draw up the piston in the syringe by the ring I, which will make a vacuum in the syringe, below the piston; and as the upper end of the tube opens into the syringe, the air will be dilated in the tube, because part of it, by its spring,

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gets up into the fyringe; and the fpring of the undilated air in the receiver acting upon the furface of the quickfilver in the jar, will force part of it up into the tube: for the quickfilver will follow the pifton in the fyringe, in the same way, and for the fame reason, that water follows the piston of a common pump when it is raised in the pump-barrel; and this, according to fome, is done by fuction. But to refute that erroneous notion, let the air be pumped out of the receiver AB, and then all the quickfilver in the tube will fall down by its own weight into the jar; and cannot be again raised one hair's breadth in the tube by working the fyringe: which shews that fuction had no hand in raising the quickfilver; and, to prove that it is done by preffure, let the air into the receiver by the cock k (Fig. 1.) and its action upon the furface of the quickfilver in the jar will raise it up into the tube, although the piston of the syringe continues motionless .- If the tube be about 32 or 33 inches high, the quickfilver will rife in it very near as high as it stands at that time in the barometer. And, if the fyringe has a fmall hole, as m, near the top of it, and the pifton be drawn up above that hole, the air will rush through the hole into the fyringe and tube, and the quickfilver will immediately fall down into the jar. If this part of the apparatus be air-tight, the quickfilver may be pumped up into the tube to the fame height that it stands in the barometer; but it will go no higher, because then the weight of the column of quickfilver in the tube is the same as the weight of a column of air, of the fame thickness with the quickfilver, reaching from the earth to the top of the atmosphere.

7. Having

Fig. 9.

7. Having placed the jar A, with some quickfilver in it, on the pump-plate, as in the last experiment, cover it with the receiver B; then push the open end of the glass tube de through the collar of leathers in the brass neck C (which it fits fo as to be air tight) almost down to the quickfilver in the jar. Then exhauft the air out of the receiver, and it will also come out of the tube, because the tube is close at top. the guage m m shews that the receiver is well exhausted, push down the tube, so as to immerse its lower end into the quickfilver in the jar. Now, although the tube be exhausted of air, none of the quickfilver will rife into it, because there is no air left in the receiver to prefs upon its furface in the jar. But let the air into the receiver by the cock k, and the quickfilver will immediately rife in the tube; and stand as high in it, as it was pumped up in the last experiment.

Both these experiments shew, that the quickfilver is supported in the barometer by the preffure of the air on its furface in the box, in which the open end of the tube is placed. And that the more dense and heavy the air is, the higher does the quickfilver rife; and, on the contrary, the thinner and lighter the air is, the more will the quickfilver fall. For if the handle F be turned ever so little, it takes some air out of the receiver, by raifing one or other of the piftons in its barrel; and confequently, that which remains in the receiver is fo much the rarer, and has fo much the lefs fpring and weight; and thereupon, the quickfilver falls a little in the tube: but upon turning the cock, and re-admitting the air into the receiver, it becomes as weighty as before, and the quickfilver rifes again to the same height.

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height.—Thus we see the reason why the quickfilver in the barometer falls before rain or snow, and rises before fair weather; for, in the former case, the air is too thin and light to bear up the vapours, and in the latter, too dense and heavy to let them fall.

N. B. In all mercurial experiments with the air-pump, a fhort pipe must be screwed into the hole i, so as to rise about an inch above the plate, to prevent the quicksilver from getting into the air-pipe and barrels, in case any of it should be accidentally spilt over the jar: for if it once gets into the pipes or barrels, it spoils them, by loosen-

ing the folder, and corroding the brafs.

8. Take the tube out of the receiver, and put one end of a bit of dry hazel branch, about an inch long, tight into the hole, and the other end tight into a hole quite through the bottom of a small wooden cup: then pour some quicksilver into the cup, and exhaust the receiver of air, and the pressure of the outward air, on the surface of the quicksilver, will sorce it through the pores of the hazel, from whence it will descend in a beautiful shower into a glass cup placed under the receiver to catch it.

9. Put a wire through the collar of leathers in the top of the receiver, and fix a bit of dry wood on the end of the wire within the receiver; then exhaust the air, and push the wire down, so as to immerse the wood into a jar of quicksilver on the pump-plate; this done, let in the air, and upon taking the wood out of the jar, and splitting it, its pores will be found full of quicksilver, which the force of the air, upon being let into the receiver, drove into the wood.

10. Join the two brass hemispherical cups A Fig. 10. and B together, with a wet leather between them, having

having a hole in the middle of it; then screw the end  $\overline{D}$  of the pipe CD into the plate of the pump at i, and turn the cock E, fo as the pipe may be open all the way into the cavity of the hemispheres: then exhaust the air out of them, and turn the cock a quarter round, which will Thut the pipe CD, and keep out the air. done, unscrew the pipe at D from the pump; and screw the piece F b upon it at D; and let two ftrong men try to pull the hemispheres asunder by the rings g and b, which they will find hard to do: for if the diameter of the hemifpheres be four inches, they will be pressed together by the external air with a force equal to 190 pounds. And to shew that it is the pressure of the air that keeps them together, hang them by either of the rings upon the hook P of the wire in the receiver M (Fig. 1.) and upon exhausting the air out of the receiver, they will fall afunder of themselves.

11. Place a small receiver O (Fig. 1.) near the hole i on the pump-plate, and cover both it and the hole with the receiver M; and turn the wire fo by the top P, that its hook may take hold of the little receiver by a ring at its top, allowing that receiver to stand with its own weight on the plate. Then, upon working the pump, the air will come out of both receivers; but the large one M will be forcibly held down to the pump by the pressure of the external air; while the small one O, having no air to press upon it, will continue loofe, and may be drawn up and let down at pleafure, by the wire PP. upon letting it quite down to the plate, and admitting the air into the receiver M, by the cock k, the air will press so strongly upon the small receiver O, as to fix it down to the plate; and at the

the fame time, by counterbalancing the outward pressure on the large receiver M, it will become loose. This experiment evidently shews, that the receivers are held down by pressure, and not by suction, for the internal receiver continued loose while the operator was pumping, and the external one was held down; but the former became fast immediately by letting in the air upon it.

into the hole of the pump-plate, and turn the cock e until the pipe be open; then put a wet leather upon the plate cd, which is fixed on the pipe, and cover it with the tall receiver GH, which is close at top: then exhaust the air out of the receiver, and turn the cock e to keep it out; which done, unscrew the pipe from the pump, and set its end A into a bason of water, and turn the cock e to open the pipe; on which, as there is no air in the receiver, the pressure of the atmosphere on the water in the bason will drive the water forcibly through the pipe, and make it play up in a jet to the top of the receiver.

13. Set the square phial A (Fig. 14.) upon the pump-plate, and having covered it with the wire cage B, put a close receiver over it, and exhaust the air out of the receiver; in doing of which, the air will also make its way out of the phial through a small hole in its neck under the valve b. When the air is exhausted, turn the cock below the plate, to re-admit the air into the receiver: and as it cannot get into the phial again, because of the valve, the phial will be broke into some thousands of pieces by the pressure of the air upon it. Had the phial been of a round form, it would have sustained this pressure.

pressure like an arch, without breaking; but as its sides are flat, it cannot.

# To show the elasticity or spring of the air.

14. Tie up a very small quantity of air in a bladder, and put it under a receiver; then exhaust the air out of the receiver; and the small quantity which is confined in the bladder (having nothing to act against it) will expand itself so by the force of its spring, as to fill the bladder as full as it could be blown of common air. But upon letting the air into the receiver again, it will overpower the air in the bladder, and press its sides almost close together.

15. If the bladder so tied up be put into a wooden box, and have 20 or 30 pound weight of lead put upon it in the box, and the box be covered with a close receiver; upon exhausting the air out of the receiver, that air which is confined in the bladder will expand itself so, as to raise up all the lead by the force of its spring.

16. Take the glass ball mentioned in the fifth experiment, which was left full of water all but a small bubble of air at top, and having set it with its neck downward into the empty phial aa, and covered it with a close receiver, exhaust the air out of the receiver, and the small bubble of air in the top of the ball will expand itself, so as to force all the water out of the ball into the phial.

17. Screw the pipe AB into the pump-plate, place the tall receiver GH upon the plate cd, as in the twelfth experiment, and exhauft the air out of the receiver; then, turn the cock e to keep out the air, unforce the pipe from the pump, and force it into the mouth of the copper veffel

Fig. 7.

Fig. 11.

veffel CC (Fig. 15.) the veffel having first been about half silled with water. Then open the cock e (Fig. 11.) and the spring of the air which is confined in the copper vessel will force the water up through the pipe AB in a jet into the exhausted receiver, as strongly as it did by its pressure on the surface of the water in a bason, in the twelfth experiment.

18. If a fowl, a cat, rat, mouse, or bird, be put under a receiver, and the air be exhausted, the animal will be at first oppressed as with a great weight, then grow convulsed, and at last expire in all the agonies of a most bitter and cruel death. But as this experiment is too shocking to every spectator who has the least degree of humanity, we substitute a machine called the lungs-glass in place of the animal.

r9. If a butterfly be fuspended in a receiver, by a fine thread tied to one of its horns, it will fly about in the receiver, as long as the receiver continues full of air; but if the air be exhausted, though the animal will not die, and will continue to flutter its wings, it cannot remove itself from the place where it hangs in the middle of the receiver, until the air be let in again, and then the animal will fly about as before.

20. Pour some quicksilver into the small bottle Fig. 12. A, and screw the brass collar c of the tube B C into the brass neck b of the bottle, and the lower end of the tube will be immersed into the quicksilver, so that the air above the quicksilver in the bottle will be confined there, because it cannot get out about the joinings, nor can it be drawn out through the quicksilver into the tube. This tube is also open at top, and is to be covered with the receiver G and large tube E F, which tube is fixed by brass collars to the receiver, and is close

at the top. This preparation being made, exhaust the air both out of the receiver and its tube; and the air will by the fame means be exhausted out of the inner tube BC, through its open top at C; and as the receiver and tubes are exhausting, the air that is confined in the glass bottle A will press so by its spring upon the furface of the quickfilver, as to force it up in the inner tube as high as it was raifed in the ninth experiment by the pressure of the atmosphere: which demonstrates that the spring of the air is

equivalent to its weight.

Fig. 13.

21. Screw the end C of the pipe CD into the hole of the pump-plate, and turn all the three cocks d, G, and H, fo as to open the communications between all the three pipes E, F, D C, and the hollow trunk AB. Then, cover the plates g and b with wet leathers, which have holes in their middle where the pipes open into the plates; and place the close receiver I upon the plate g: this done, thut the pipe F by turning the cock H, and exhauft the air out of the receiver I. Then, turn the cock d to shut out the air, unfcrew the machine from the pump, and having screwed it to the wooden foot L, put the receiver K upon the plate b; this receiver will continue loofe on the plate as long as it keeps full of air; which it will do until the cock H be turned to open the communication between the pipes F and E, through the trunk AB; and then the air in the receiver K, having nothing to act against its spring, will run from K into I, until it be so divided between these receivers, as to be of equal density in both; and then they will be held down with equal forces to their plates by the pressure of the atmosphere; though each receiver will then be kept down but with one half

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half of pressure upon it, that the receiver I had, when it was exhausted of air; because it has now one half of the common air in it which filled the receiver K when it was set upon the plate; and therefore a storce equal to half the force of the spring of common air, will act within the receivers against the whole pressure of the common air upon their outsides. This is called transferring the air out of one vessel into another.

22. Put a cork into the square phial A, and Fig. 14. fix it in with wax or cement; put the phial upon the pump-plate with the wire cage B over it, and cover the cage with a close receiver. Then, exhaust the air out of the receiver, and the air that was corked up in the phial will break the phial by the force of its spring, because there is no air left on the outside of the phial to act against the air within it.

23. Put a shrivelled apple under a close receiver, and exhaust the air; then the spring of the air within the apple will plump it out, so as to cause all the wrinkles to disappear; but upon letting the air into the receiver again, to press upon the apple, it will instantly return to its former decayed and shrivelled state.

24. Take a fresh egg, and cut off a little of the shell and film from its smallest end, then put the egg under a receiver, and pump out the air; upon which, all the contents in the egg will be forced out into the receiver, by the expansion of a small bubble of air contained in the great end, between the shell and film.

25. Put some warm beer into a glass, and having set it on the pump, cover it with a close receiver, and then exhaust the air. While this is doing, and thereby the pressure more and more

taken off from the beer in the glass, the air therein will expand itself, and rife up in innumerable
bubbles to the surface of the beer; and from
thence it will be taken away with the other air in
the receiver. When the receiver is nearly exhausted, the air in the beer, which could not
disentangle itself quick enough to get off with
the rest, will now expand itself so, as to cause
the beer to have all the appearance of boiling;
and the greatest part of it will go over the
glass.

26. Put some warm water into a glass, and put a bit of dry wainscot or other wood into the water. Then, cover the glass with a close receiver, and exhaust the air; upon which, the air in the wood having liberty to expand itself, will come out plentifully, and make all the water to bubble about the wood, especially about the ends, because the pores lie lengthwise. A cubic inch of dry wainscot has so much air in it, that it will continue bubbling for near half an hour

# Miscellaneous Experiments.

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27. Screw the fyringe H (Fig. 8.) to a piece of lead that weighs one pound at least; and, holding the lead in one hand, pull up the piston in the fyringe with the other; then, quitting hold of the lead, the air will push it upward, and drive back the fyringe upon the piston. The reason of this is, that the drawing up of the piston makes a vacuum in the fyringe, and the air, which presses every way equally, having nothing to resist its pressure upward, the lead is thereby pressed upward, contrary to its natural tendency by gravity. If the syringe, so loaded, be

be hung in a receiver, and the air be exhausted, the fyringe and lead will descend upon the pistonrod by their natural gravity; and, upon admitting the air into the receiver, they will be drove upward again, until the piston be at the very

bottom of the fyringe.

28. Let a large piece of cork be suspended by a thread at one end of a balance, and counterpoised by a leaden weight, suspended in the fame manner, at the other. Let this balance be hung to the infide of the top of a large receiver; which being fet on the pump, and the air exhausted, the cork will preponderate, and shew itself to be heavier than the lead; but upon letting in the air again, the equilibrium will be restored. The reason of this is, that since the air is a fluid, and all bodies lose as much of their absolute weight in it, as is equal to the weight of their bulk of the fluid, the cork being the larger body, loses more of its real weight than the lead does; and therefore must in fact be heavier, to balance it under the disadvantage of losing some of its weight: which disadvantage being taken off by removing the air, the bodies then gravitate according to their real quantities of matter, and the cork, which balanced the lead in air, shews itself to be heavier when in vacuo.

29. Set a lighted candle upon the pump, and cover it with a tall receiver. If the receiver holds a gallon, the candle will burn a minute; and then, after having gradually decayed from the first instant, it will go out: which shews, that a constant supply of fresh air is necessary to feed slame; and so it also is for animal life. For a bird kept under a close receiver will soon die, although no air be pumped out; and it is

found that, in the diving-bell, a gallon of air is sufficient only for one minute for a man to breathe in.

The moment when the candle goes out, the smoke will be seen to ascend at the top of the receiver, and there it will form a fort of cloud: but upon exhausting the air, the smoke will fall down to the bottom of the receiver, and leave it as clear at the top as it was before it was set upon the pump. This shews, that smoke does not ascend on account of its being positively light, but because it is lighter than air; and its falling to the bottom when the air is taken away, shews, that it is not destitute of weight. So most forts of wood ascend or swim in water; and yet there are none who doubt of the wood's having gravity or weight.

30. Set a receiver, which is open at top, upon the air-pump, and cover it with a brass plate, and wet leather; and having exhausted it of air, let the air in again at top through an iron pipe, making it pass through a charcoal flame at the end of the pipe; and when the receiver is full of that air, lift up the cover, and let down a mouse or bird into the receiver, and the burnt air will immediately kill it. If a candle be let down into that air, it will go out directly; but, by letting it down gently, it will purify the air so far as it goes; and so, by letting it down more and more, the flame will drive out the bad air,

and good air will get in.

31. Set a bell upon a cushion on the pumpplate, and cover it with a receiver; then shake the pump to make the clapper strike against the bell, and the sound will be very well heard: but, exhaust the receiver of air, and then, if the clapper be made to strike ever so hard against

the

the bell, it will make no found at all; which shews, that air is absolutely necessary for the pro-

pagation of found.

32. Let a candle be placed on one fide of a receiver, and viewed through the receiver at fome distance; then, as soon as the air begins to be exhausted, the receiver will be filled with vapours which rise from the wet leather, by the spring of the air in it; and the light of the candle being refracted through that medium of vapours, will have the appearance of circles of various colours, of a faint resemblance to those in the rain-bow.

The air-pump was invented by Otho Guerick of Magdeburg, but was much improved by Mr. Boyle, to whom we are indebted for our greatest part of the knowledge of the wonderful properties of the air, demonstrated in the above experiments.

The elastic air which is contained in many bodies, and is kept in them by the weight of the atmosphere, may be got out of them either by boiling, or by the air-pump, as shewn in the 25th experiment: but the fixed air, which is by much the greater quantity, cannot be got out but by distillation, fermentation, or putrefaction.

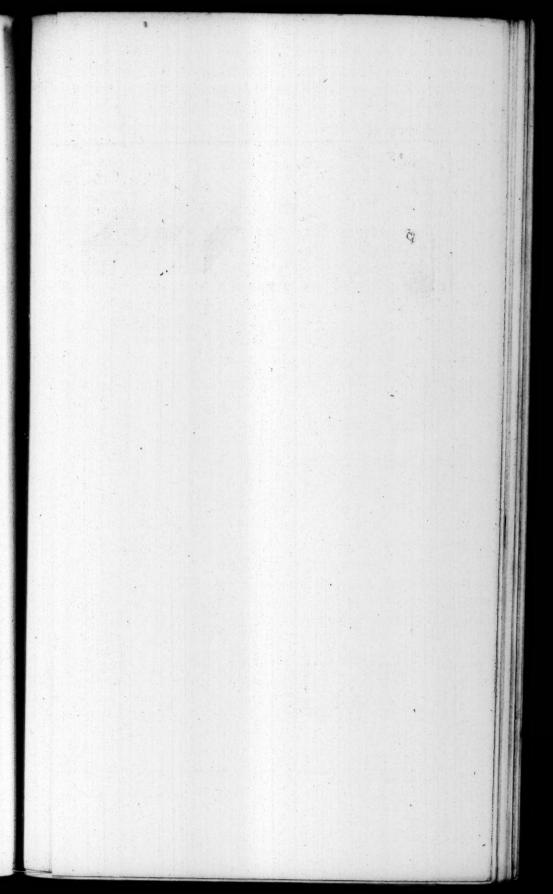
If fixed air did not come out of bodies with difficulty, and spend some time in extricating itself from them, it would tear them to pieces. Trees would be rent by the change of air from a fixt, to an elastic state, and animals would be burst in pieces by the explosion of air in their food.

Dr. Hales found by experiment, that the air in apples is fo much condenfed, that if it were let out into the common air, it would fill a space

48 times as great as the bulk of the apples themselves; so that its pressure was equal to 11776 lb. and in a cubic inch of oak, to 19860 lb. against their sides. So that if the air was let loose at once in these substances, they would tear every thing to pieces about them with a force superior to that of gunpowder. Hence, in eating apples, it is well that they part with the air by degrees, as they are chewed, and ferment in the stomach, otherwise an apple would be immediate death to him who eats it.

The mixing of fome substances with others will release the air from them, all of a sudden, which may be attended with very great danger. Of this we have a remarkable instance in an experiment made by Dr. Slare; who having put half a dram of oil of carraway-feed into one glass, and a dram of compound spirit of nitre in another, covered them both on the air-pump with a receiver fix inches wide, and eight inches deep, and then exhausted the air, and continued pumping until all that could possibly be got both out of the receiver, and out of the two fluids, was extricated: then, by a particular contrivance from the top of the receiver, he mixed the fluids together; upon which they produced fuch a prodigious quantity of air, as instantly blew up the receiver, although it was pressed down by the atmosphere with upward of 400 pounds weight.

N. B. In the 28th experiment, the cork must be covered all over with a piece of thin wet bladder glued to it, and not used until it be thoroughly dry.



Confuseular

#### LECT. VIII.

## Of Optics.

IGHT consists of an inconceivably great number of particles flowing from a luminous body in all manner of directions; and these particles are fo fmall, as to furpass all human

comprehension.

That the number of particles of light is inconceivably great, appears from the light of a candle; which, if there be no obstacle in the way to obstruct the passage of its rays, will fill all the space within two miles of the candle, every way, with luminous particles, before it has loft

the least sensible part of its substance.

A ray of light is a continued stream of these particles, flowing from any visible body in a straight line: and that the particles themselves are incomprehenfibly small, is manifest from the following experiment. Make a small pin hole in a piece of black paper, and hold the paper upright on a table facing a row of candles standing by one another; then place a sheet of pasteboard at a little distance behind the paper, and some of the rays which flow from all the candles through the hole in the paper, will form as many specks of light on the pasteboard, as there are candles on the table before the plate: each speck The amabeing as distinct and clear, as if there was only zing one speck from one single candle: which shews, of the that the particles of light are exceedingly finall, particles otherwise they could not pass through the hole of the from fo many different candles without continfion.—Dr. Niewentyt has computed, that the flows more than 6,000,000,000 times

many particles of light from a candle in one fecond of time, as there are grains of fand in the whole earth, fupposing each cubic inch of it to

contain 1,000,000.

These particles, by falling directly upon our eyes, excite in our minds the idea of light. And when they fall upon bodies, and are thereby reflected to our eyes, they excite in us the ideas of these bodies. And as every point of a visible body reflects the rays of light in all manner of directions, every point will be visible in every part to which the light is reflected from it. Plate XV. Thus the object ACB is visible to an eye in any

Fig. 1.

Reflected

light.

part where the rays Aa, Ab, Ac, Ad, Ae, Ba, Bb, Bc, Bd, Be, and Ca, Cb, Cc, Cd, Ce, come. Here we have shewn the rays as if they were only reflected from the ends A and B, and from the middle point C of the object; every other point being supposed to reflect rays in the same manner. So that wherever a spectator is placed with regard to the body, every point of that part of the furface which is toward him will be visible, when no intervening object stops the passage of the light.

As no object can be seen through the bore of a bended pipe, it is evident that the rays of light move in straight lines, while there is nothing to refract or turn them out of their recti-

lineal course.

While the rays of light continue in any \* medium of an uniform density, they are straight; but when they pass obliquely out of one medium into another, which is either more dense or more

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b

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<sup>\*</sup> Any thing through which the rays of light can pass, is called a medium; as air, water, glass, diamond, or even a vacuum.

rare, they are refracted toward the denfer medium: and this refraction is more or less, as the rays fall more or less obliquely on the refracting furface which divides the mediums.

To prove this by experiment, set the empty Fig. 2. vessel ABCD into any place where the sun shines obliquely, and observe the part where the shadow of the edge BC falls on the bottom of the vessel at E; then sill the vessel with water, and the shadow will reach no farther than e; which shews, that the ray a BE, which came straight in the open air, just over the edge of the vessel at B to its bottom at E, is refracted by salling obliquely on the surface of the water at Restacted B; and instead of going on in the rectilineal dilight. rection a BE, it is bent downward in the water from B to e; the whole bend being at the surface of the water: and so of all the other rays a b c.

If a flick be laid over the vessel, and the sun's rays be reslected from a glass perpendicularly into the vessel, the shadow of the slick will fall upon the same part of the bottom, whether the vessel be empty or full, which shews, that the rays of light are not resracted when they fall perpendi-

cularly on the furface of any medium.

The rays of light are as much refracted by passing out of water into air, as by passing out of air into water. Thus, if a ray of light flows from the point e, under water, in the direction e B; when it comes to the surface of the water at B, it will not go on thence in the rectilineal course B d, but will be refracted into the line B a. Therefore,

To an eye at e looking through a plane glass in the bottom of the empty vessel, the point a cannot be seen, because the side Bc of the vessel

interposes; and the point d will just be seen over the edge of the vessel at B. But if the vessel be filled with water, the point a will be feen from e: and will appear as at d, elevated in the direction

The time of fun-rifing or fetting, supposing

of the ray e B\*.

The days

are made its rays suffered no refraction, is easily found by longer by calculation. But observation proves that the tion of the fun rifes fooner, and fets later every day than the fun's rays. calculated time; the reason of which is plain, from what was faid immediately above. For, though the fun's rays do not come part of the way to us through water, yet they do through the air or atmosphere, which being a groffer medium than the free space between the sun and the top of the atmosphere, the rays, by entering obliquely into the atmosphere, are there refracted, and thence bent down to the earth. And although there are many places of the earth to which the fun is vertical at noon, and confequently his rays can fuffer no refraction at that time, because they come perpendicularly through the atmosphere: yet there is no place to which the fun's rays do not fall obliquely on the top of the atmosphere, at his rifing and fetting; and confequently, no clear day in which the fun will not be visible before he rises in the horizon, and after he sets in it: and the longer or shorter, as the atmosphere is more or less replete with vapours. For, let ABC be part of the earth's furface, DEF the atmosphere that covers it,

Fig. 3.

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<sup>\*</sup> Hence a piece of money lying at e, in the bottom of an empty vessel, cannot be seen by an eye at a, because the edge of the veffel intervenes; but let the veffel be filled with water, and the ray ea being then refracted at B, will strike the eye at a, and fo render the money visible, which will appear as if it were raised up to f in the line a B f.

and EBGH the fensible horizon of an observer at B. As every point of the sun's surface sends out rays of light in all manner of directions, some of his rays will constantly fall upon, and enlighten, some half of the atmosphere; and therefore, when the sun is at I, below the horizon H, those rays which go on in the free space IkK preserve a rectilineal course until they fall upon the top of the atmosphere, and those which fall so about K, are refracted at their entrance into the atmosphere, and bent down in the line KmB, to the observer's place at B: and therefore, to him, the sun will appear at L, in the direction of the ray BmK, above the horizon BGH, when he is really below it at I.

The angle contained between a ray of light, and a perpendicular to the refracting furface, is called the angle of incidence; and the angle con-Angle of tained between the same perpendicular, and the incidence. same ray after refraction, is called the angle of refraction. Thus, let LBM be the refracting Angle of surface of a medium (suppose water) and ABC refraction. a perpendicular to that surface: let DB be a Fig. 4-ray of light, going out of air into water at B, and therein refracted in the line BH; the angle ABD, is the angle of incidence, of which DF is the sine; and the angle KBH is the angle of

refraction, whose fine is K I.

When the refracting medium is water, the fine of the angle of incidence is to the fine of the angle of refraction, as 4 to 3; which is confirmed by the following experiment, taken from

Doctor Smith's Optics.

Describe the circle DAEC on a plane square board, and cross it at right angles with the straight lines ABC, and LBM; then, from the intersection A, with any opening of the com-

passes, set off the equal arcs AD and AE, and draw the right line DFE: then, taking Fa. which is three quarters of the length FE, from the point a, draw a I parallel to ABK, and join KI parallel to BM: fo KI will be equal to three quarters of FE or of DF. This done, fix the board upright upon the leaden pedeftal O, and flick three pins perpendicularly into the board, at the points D, B, and 1: then fet the board upright into the vessel VUT, and fill up the vessel with water to the line LBM. When the water has fettled, look along the line DB, fo as you may fee the head of the pin B over the head of the pin D; and the pin I will appear in the fame right line produced to G, for its head will be feen just over the head of the pin at B: which shews that the ray IB, coming from the pin at I, is so refracted at B, as to proceed from thence in the line BD to the eve of the observer; the same as it would do from any point G in the right line DBG, if there were no water in the vessel: and also shews that KI, the sine of refraction in water, is to DF, the fine of incidence in air, as 3 to 4\*.

Hence, if DBH were a crooked flick put obliquely into the water, it would appear a flraight one, as DBG. Therefore, as the line BH appears at BG, so the line BG will appear at Bg; and consequently, a flraight flick DBG put obliquely into water, will seem bent at the surface of the water in B, and crooked, as DBg.

When a ray of light passes out of air into glass, the fine of incidence is to the fine of re-

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<sup>\*</sup> This is strictly true of the red rays only, for the other coloured rays are differently refracted; but the difference is so small, that it need not be considered in this place.

raction, as 3 to 2; and when out of air into a amond, as 5 to 2.

Glass may be ground into eight different Fig. 5.

hapes at least, for optical purposes, viz.

1. A plane glass, which is flat on both fides, and of equal thickness in all its parts, as A.

2. A plano-convex, which is flat on one fide, Lenfes,

ad convex on the other, as B.

3. A double convex, which is convex on both files, as C.

4. A plano-concave, which is flat on one fide, and concave on the other, as D.

5. A double concave, which is concave on both sides, as E.

6. A meniscus, which is concave on one fide, and convex on the other, as F.

7. A flat plano-cenvex, whose convex side is ground into several little flat surfaces, as G.

8. A prism, which has three flat fides, and when viewed endwise, appears like an equilateral triangle, as H.

Glasses ground into any of the shapes B, C, D,

I, F, are generally called lenses.

A right line LIK, going perpendicularly through the middle of a lens, is called the axis of the lens.

A ray of light Gb, falling perpendicularly on a plane glass EF, will pass through the glass in Fig. 6, the same direction bi, and go out of it into the

air in the same right course i H.

A ray of light A B, falling obliquely on a plane glass, will go out of the glass in the same direction, but not in the same right line; for in touching the glass, it will be refracted in the line B C, and in leaving the glass, it will be refracted in the line CD.

Fig. 7.

A ray of light CD, falling obliquely on the middle of a convex glass, will go forward in the fame direction DE, as if it had fallen with the fame degree of obliquity on a plane glass; and will go out of the glass in the same direction with which it entered: for it will be equally rifracted at the points D and E, as if it had passed through a plane furface. But the rays CG and CI will be so refracted, as to meet again at the point F. Therefore, all the rays which flow from the point C, so as to go through the glas, will meet again at F: and if they go farther onward, as to L, they cross at F, and go folward on the opposite sides of the middle ray CDEF, to what they were in approaching it in the directions HF and KF.

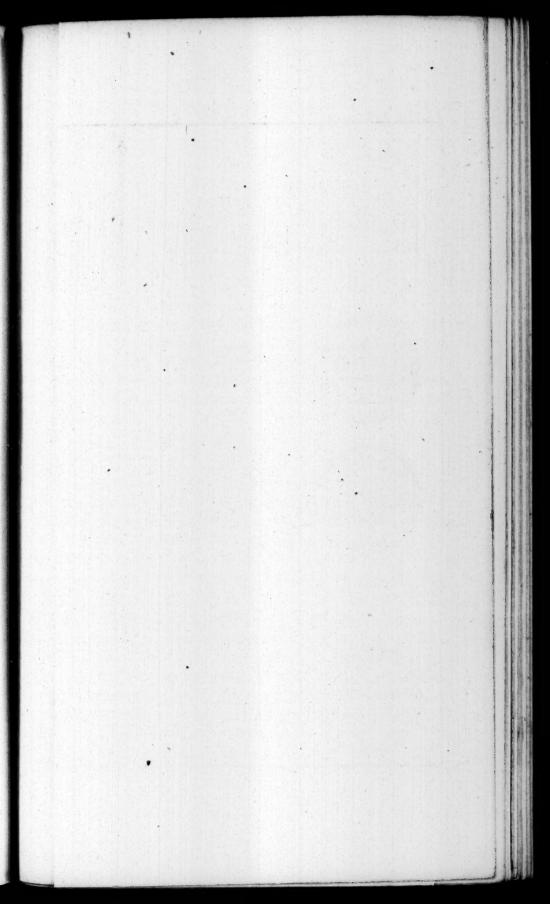
Fig. 8. The properties of different lenfes.

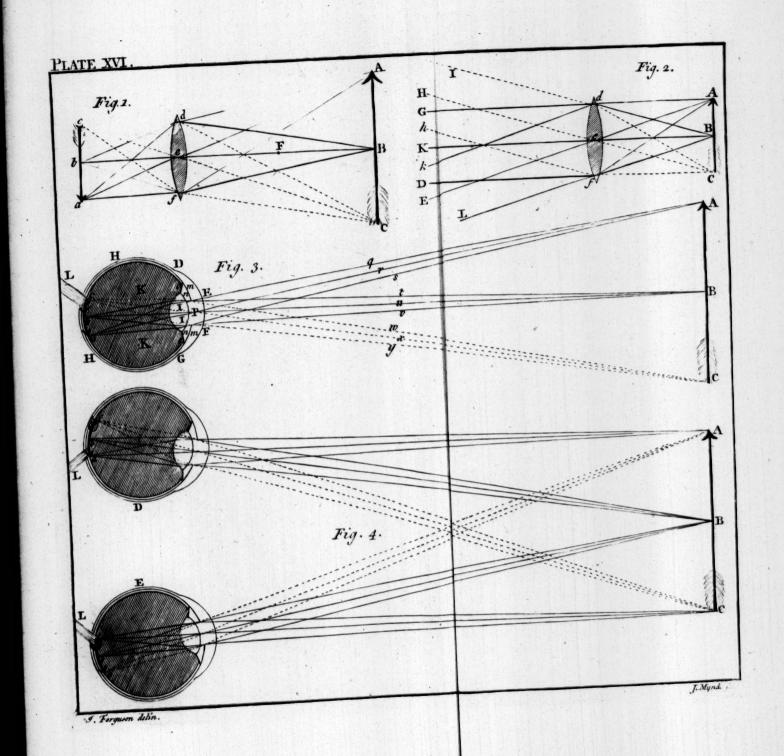
When parallel rays, as ABC, fall directly upon a plano-convex glass DE, and pass through it, they will be fo refracted, as to unite in a point f behind it: and this point is called the principal focus: the distance of which, from the middle of the glass, is called the focal distance; which is equal to twice the radius of the fphere

of the glass's convexity. And,

Fig. 9.

When parallel rays, as ABC, fall directly upon a glass DE, which is equally convex on both fides, and pass through it; they will be so refracted, as to meet in a point or principal focus f, whose distance is equal to the radius or semidiameter of the sphere of the glass's convexity. But if a glass be more convex on one side than on the other, the rule for finding the focal distance is this; as the sum of the semidiameters of both convexities is to the femidiameter of either, so is double the semidiameter of the other to the distance of the focus. Or, divide





the double product of the radii by their fum, and the quotient will be the distance fought.

Since all those rays of the sun which pass through a convex glass are collected together in its focus, the force of all their heat is collected into that part; and is in proportion to the common heat of the sun, as the area of the glass is to the area of the focus. Hence we see the reason why a convex glass causes the sun's rays to burn after passing through it.

All these rays cross the middle ray in the socus f, and then diverge from it, to the contrary sides, in the same manner F f G, as they converged in the space D f E in coming to it.

If another glass FG, of the same convexity as DE, be placed in the rays at the same distance from the socus, it will restract them so, as that after going out of it, they will be all parallel, as abc; and go on in the same manner as they came to the first glass DE, through the space ABC; but on the contrary sides of the middle ray Bfb: for the ray ADf will go on from f in the direction fGa, and the ray CEf in the direction fFc; and so of the rest.

The rays diverge from any radiant point, as from a principal focus: therefore, if a candle be placed at f, in the focus of the convex glass FG, the diverging rays in the space FfG will be so refracted by the glass, as, that after going out of it, they will become parallel, as shewn in the space f, f

the space cba.

If the candle be placed nearer the glass than its focal distance, the rays will diverge after passing through the glass, more or less, as the candle is more or less distant from the focus.

If the candle be placed farther from the glass than its focal distance, the rays will converge

after passing through the glass, and meet in a point which will be more or less distant from the glass, as the candle is nearer to, or farther from its focus; and where the rays meet, they will form an inverted image of the slame of the candle; which may be seen on a paper placed in the meeting of the rays.

Plate XVI. Fig. 1.

Hence, if any object ABC be placed beyond the focus F of the convex glass def, some of the rays which flow from every point of the object, on the fide next the glass, will fall upon it, and after paffing through it, they will be converged into as many points on the opposite fide of the glass, where the image of every point will be formed: and consequently, the image of the whole object, which will be inverted. Thus, the rays Ad, Ae, Af, flowing from the point A, will converge in the space daf, and by meeting at a, will there form the image of the point A. The rays Bd, Be, Bf, flowing from the point B, will be united at b by the refraction of the glass, and will there form the image. of the point B. And the rays Cd, Ce, Cf, flowing from the point C, will be united at  $\epsilon$ , where they will form the image of the point C. And fo of all the other intermediate points between A and C. The rays which flow from every particular point of the object, and are united again by the glass, are called pencils of rays.

If the object ABC be brought nearer to the glass, the picture abc will be removed to a greater distance. For then, more rays flowing from every single point, will fall more diverging upon the glass; and therefore cannot be so foon collected into the corresponding points behind it. Consequently, if the distance of the object

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ABC be equal to the distance e B of the focus Fig. 2. of the glass, the rays of each pencil will be so refracted by paffing through the glass, that they will go out of it parallel to each other; as d I, eH, fh, from the point C; dG, eK, fD, from the point B; and dK, eE, fL, from the point A: and therefore, there will be no picture formed behind the glass.

If the focal distance of the glass, and the distance of the object from the glass, be known, the distance of the picture from the glass may be found by this rule, viz. multiply the distance of the focus by the distance of the object, and divide the product by their difference; the quotient will

be the distance of the picture.

The picture will be as much bigger or less Fig. 14 than the object, as its diffance from the glass is greater or less than the distance of the object. For, as Be is to eb, fo is AC to ca. So that if ABC be the object, cba will be the picture; or, if cba be the object, ABC will be the

picture.

Having described how the rays of light, flow- The many ing from objects, and passing through convex ner of glasses, are collected into points, and form the vision, images of the objects; it will be easy to underfland how the rays are affected by passing through the humours of the eye, and are thereby collected into innumerable points on the bottom of the eye, and thereon form the images of the objects which they flow from. For, the different humours of the eye, and particularly the chrystalline humour, are to be confidered as a convex glass; and the rays in passing through them to be affected in the fame manner as in passing through a convex glass. The P

Fig. 3.

from them.

The eye is nearly globular. It confifts of The eye described three coats and three humours. The part DHHG of the outer coat, is called the selerotica, the rest DEFG the cornea. Next within this coat is that called the choroides, which serves as it were for a lining to the other, and joins with the iris mn, mn. The iris is composed of two fets of muscular fibres; the one of a circular form, which contracts the hole in the middle called the pupil, when the light would otherwife be too ftrong for the eye; and the other of radical fibres, tending every where from the circumference of the iris toward the middle of the pupil; which fibres, by their contraction, dilate and enlarge the pupil when the light is weak, in order to let in the more of its rays, The third coat is only a fine expansion of the optic nerve L, which spreads like net-work all over the infide of the choroides, and is therefore called the retina; upon which are painted (as it were) the images of all visible objects, by the rays of light which either flow or are reflected

> Under the cornea is a fine transparent fluid. like water, which is therefore called the aqueous bumour. It gives a protuberant figure to the cornea, fills the two cavities mm and nn, which communicate by the pupil P, and has the fame limpidity, specific gravity, and refractive power as water. At the back of this lies the chrystalline bumour II, which is shaped like a double convex glass; and is a little more convex on the back than the fore-part. It converges the rays, which pass through it from every visible object to its focus at the bottom of the eye. This humour is transparent like chrystal, is much of the confistence of hard jelly, and exceeds the specific

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specific gravity of water in the proportion of 11 to 10. It is inclosed in a fine transparent membrane, from which proceed radial fibres 00, called the ligamentum ciliare, all around its edge; and join to the circumference of the iris. These fibres have a power of contracting and dilating occasionally, by which means they alter the shape or convexity of the chrystalline humour, and also shift it a little backward or forward in the eye, so as to adapt its socal distance at the bottom of the eye to the different distances of objects; without which provision, we could only see those objects distinctly, that were all at one distance from the eye.

At the back of the chrystalline, lies the vitreous humour KK, which is transparent like glass, and is largest of all in quantity, filling the whole orb of the eye, and giving it a globular shape. It is much of a consistence with the white of an egg, and very little exceeds the specific gravity

and refractive power of water.

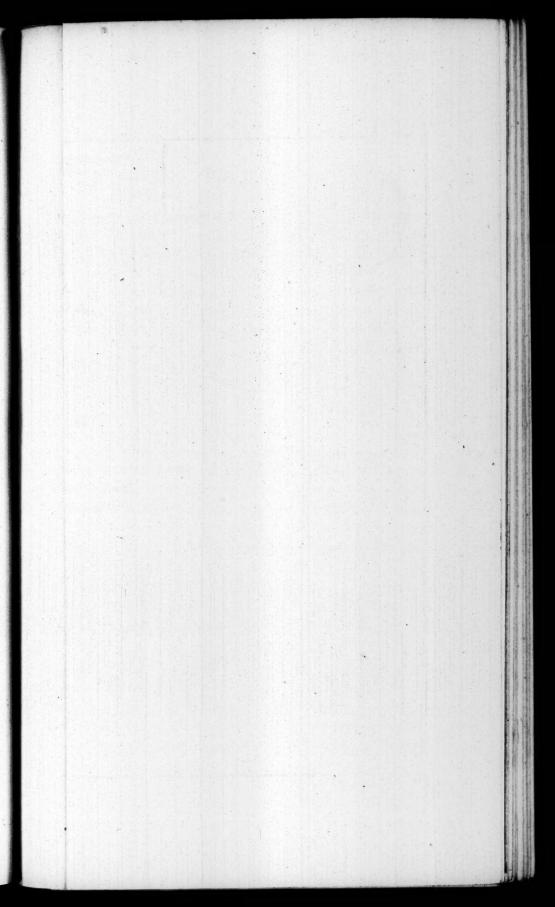
As every point of an object: ABC fends out rays in all directions, fome rays, from every point on the fide next the eye, will fall upon the cornea between E and F; and by passing on through the humours and pupil of the eye, they will be converged to as many points on the retina or bottom of the eye, and will thereon form a distinct inverted picture cba of the object. Thus, the pencil of rays qrs, that flows from the point A of the object, will be converged to the point a on the retina; those from the point B will be converged to the point b; those from the point C will be converged to the point c; and fo of all the intermediate points: by which means the whole image abc is formed, and the object made visible; although it must

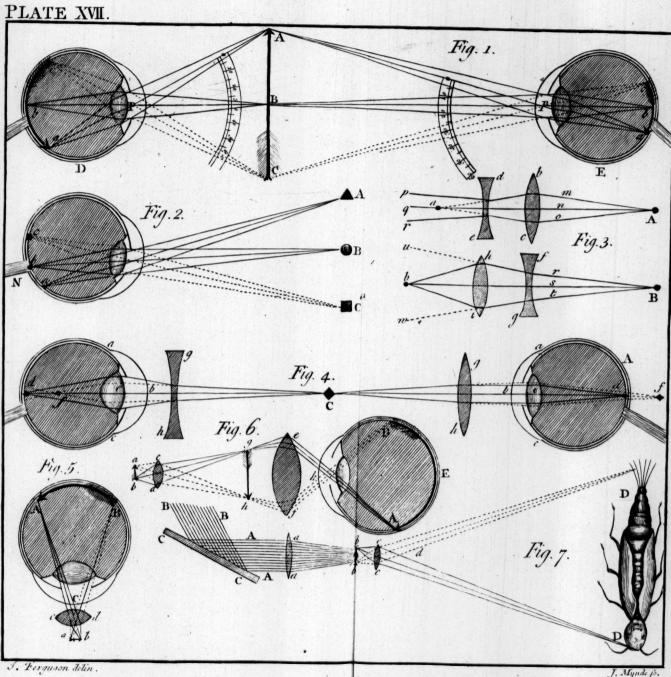
be owned, that the method by which this fenfation is carried from the eye by the optic nerve to the common fenfory in the brain, and there differenced, is above the reach of our comprehenfion.

But that vision is effected in this manner, may be demonstrated experimentally. Take a bullock's eye while it is fresh, and having cut off the three coats from the back part, quite to the vitreous humour, put a piece of white paper over that part, and hold the eye toward any bright object, and you will see an inverted pic-

ture of the object upon the paper.

Seeing the image is inverted, many have wondered why the object appears upright. But we are to consider, 1. That inverted is only a relative term: and 2. That there is a very great difference between the real object and the means or image by which we perceive it. When all the parts of a distant prospect are painted upon the retina, they are all right with respect to one another, as well as the parts of the prospect itself; and we can only judge of an object's being inverted, when it is turned reverse to its natural position, with respect to other objects which we fee and compare it with.—If we lay hold of an upright flick in the dark, we can tell which is the upper or lower part of it, by moving our hand upward or downward; and know very well that we cannot feel the upper end by moving our hand downward. Just so we find by experience, that upon directing our eyes toward a tall object, we cannot fee its top by turning our eyes downward, nor its foot by turning our eyes upward; but must trace the object the same way by the eye to see it from head to foot, as we do by the hand to feel it; and





and as the judgment is informed by the motion of the hand in one case, so it is also by the motion of the eye in the other.

In Fig. 4. is exhibited the manner of feeing Fig. 4. the same object ABC, by both the eyes D and

E at once.

When any part of the image cba falls upon the optic nerve L, the corresponding part of the object becomes invisible. On which account nature has wifely placed the optic nerve of each eye, not in the middle of the bottom of the eye, but toward the fide next the nofe; fo that whatever part of the image falls upon the optic nerve of one eye, may not fall upon the optic nerve of the other. Thus the point a of the image cba falls upon the optic nerve of the eye D, but not of the eye E; and the point e falls upon the optic nerve of the eye E, but not of the eye D: and therefore to both eyes taken together, the whole object ABC is visible.

The nearer that any object is to the eye, the Plate larger is the angle under which it is feen, and XVII. the magnitude under which it appears. to the eye D, the object ABC is feen under the angle APC; and its image cba is very large upon the retina: but to the eye E, at a double distance, the same object is seen under the angle Ap C, which is equal only to half the angle APC, as is evident by the figure. The image cba is likewife twice as large in the eye D, as the other image cba is in the eye E. In both these representations, a part of the image falls on the optic nerve, and the object in the corre-

fponding part is invisible.

As the fense of seeing is allowed to be occafioned by the impulse of the rays from the visible object upon the retina of the eye, and forming

the image of the object thereon, and that the retina is only the expansion of the optic nerve all over the choroides; it should feem furprising that the part of the image which falls on the optic nerve should render the like part of the object invisible; especially as that nerve is allowed to be the instrument by which the impulse and image are conveyed to the common fenfory in the brain. But this difficulty vanishes, when we consider that there is an artery within the trunk of the optic nerve, which entirely obscures the image in that part, and conveys no fensation to the brain.

That the part of the image which falls upon the middle of the optic nerve is loft, and confequently the corresponding part of the object is rendered invisible, is plain by experiment. For, if a person fixes three patches, A, B, C, horizontally, upon a white wall, at the height of the eye, and the distance of about a foot from each other, and places himself before them, shutting the right eye, and directing the left toward the patch C, he will fee the patches A and C, but the middle patch B will disappear. Or, if he shuts his left eye, and directs the right toward A, he will fee both A and C, but B will disappear; and if he directs his eye toward B, he will fee both B and A, but not C. For whatever patch is directly opposite to the optic nerve N, vanishes. requires a little practice, after which he will find it easy to direct his eye, so as to lose the fight of which ever patch he pleases.

We are not commonly fensible of this disappearance, because the motions of the eye are fo quick and inftantaneous, that we no fooner lofe the fight of any part of an object, than we recover it again; much the same as in the twinkling of our eyes, for at each twinkling we

Fig. 2.

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are blinded; but it is so soon over, that we are scarce ever sensible of it.

Some eyes require the affiftance of convex Fig. 4. glasses to make them see objects distinctly, and Why others of concave. If either the cornea abc or fome eyes chrystalline humour e, or both of them, be too spectacles. flat, as in the eye A, their focus will not be on the retina, as at d, where it ought to be, in order to render vision distinct; but beyond the eye, as at f. Confequently those rays which flow from the object C, and pass through the humours of the eye, are not converged enough to unite at d; and therefore the observer can have but a very indistinct view of the object. This is remedied by placing a convex glass g b before the eye, which makes the rays converge fooner, and imprints the image duly on the retina at d.

If either the cornea, or chrystalline humour, or both of them, be too convex, as in the eye f, the rays that enter in from the object C, will be converged to a focus in the vitreous humour, as at f; and by diverging from thence to the retina, will form a very confused image thereon: and so, of course, the observer will have as confused a view of the object, as if his eye had been too slat. This inconvenience is remedied by placing a concave glass g b before the eye; which glass, by causing the rays to diverge between it and the eye, lengthens the focal distance so, that if the glass be properly chosen, the rays will unite at the retina, and form a distinct picture of the object upon it.

Such eyes as have their humours of a due convexity, cannot fee any object distinctly at a less distance than six inches; and there are numberless objects too small to be seen at that

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distance,

Fig. 5.

distance, because they cannot appear under any The method of viewing fuch fenfible angle. minute objects is by a microscope, of which there are three forts, viz. the fingle, the double, and the folar.

The fingle microscope, is only a small convex The fingle glass, as cd, having the object ab placed in its microscope. focus, and the eye at the same distance on the other fide; fo that the rays of each pencil, flowing from every point of the object on the fide next the glass, may go on parallel in the space between the eye and the glass; and then, by entering the eye at C, they will be converged to as many different points on the retina, and form a large inverted picture AB upon it, as in the figure.

To find how much this glass magnifies, divide the least distance (which is about six inches) at which an object can be feen distinctly with the bare eye, by the focal distance of the glass; and the quotient will shew how much the glass mag-

nifies the diameter of the object.

Fig. 6. microscope.

The double or compound microscope, consists of The double an object-glass ed, and an eye-glass ef. fmall object ab is placed at a little greater diftance from the glass cd than its principal focus, fo that the pencils of rays flowing from the different points of the object, and paffing through the glass, may be made to converge and unite in as many points between g and b, where the image of the object will be formed: which image is viewed by the eye through the eyeglass ef. For the eye glass being so placed, that the image gb may be in its focus, and the eye much about the fame distance on the other fide, the rays of each pencil will be parallel, after going out of the eye-glass, as at e and A

till they come to the eye at k, where they will begin to converge by the refractive power of the humours; and after having croffed each other in the pupil, and passed through the chrystalline and vitreous humours, they will be collected into points on the retina, and form the

large inverted image AB thereon.

The magnifying power of this microscope is as follows. Suppose the image gb to be fix times the distance of the object ab from the object-glass cd; then will the image be fix times the length of the object: but fince the image could not be feen diffinctly by the bare eye at a less distance than six inches, if it be viewed by an eye-glass ef, of one inch focus, it will thereby be brought fix times nearer the eye; and confequently viewed under an angle fix times as large as before; fo that it will be again magnified fix times; that is, fix times by the object-glass, and fix times by the eye-glass, which multiplied into one another, makes 36 times; and fo much is the object magnified in diameter more than what it appears to the bare eye; and confequently 36 times 36, or 1296 times in surface.

But because the extent or field of view is very small in this microscope, there are generally two eye-glasses placed sometimes close together, and sometimes an inch asunder; by which means, although the object appears less magnified, yet the visible area is much enlarged by the interposition of a second eye-glass; and consequently a much pleasanter view is obtained.

The folar microscope, invented by Dr. Lie-Fig. 7. burkbun, is constructed in the following manner. The folar Having procured a very dark room, let a round microscope. hole be made in the window-shutter, about three inches

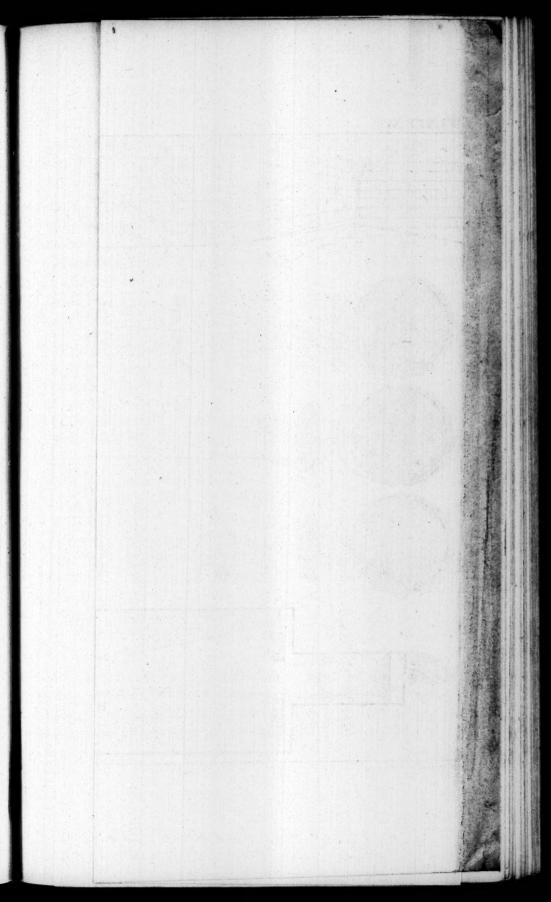
inches diameter, through which the sun may cast a cylinder of rays A A into the room. In this hole place the end of a tube, containing two convex glasses and an object, viz. 1. A convex glass a a, of about two inches diameter, and three inches focal distance, is to be placed in that end of the tube which is put into the hole. 2. The object b b, being put between two glasses (which must be concave to hold it at liberty) is placed about two inches and a half from the glass a a. 3. A little more than a quarter of an inch from the object is placed the snall convex glass c c, whose focal distance is a quarter of an inch.

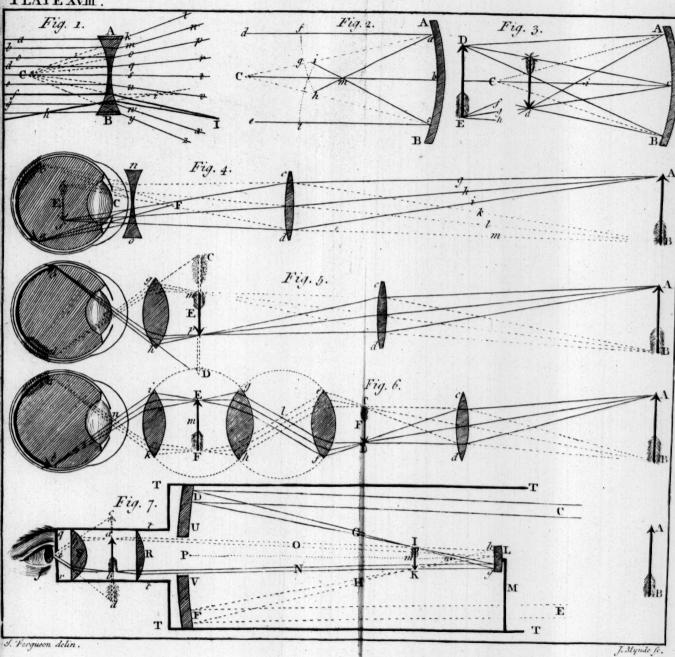
The tube may be so placed, when the sun is low, that his rays AA may enter directly into it: but when he is high, his rays BB must be reflected into the tube by the plane mirror or

looking-glass CC.

Things beings thus prepared, the rays that enter the tube will be conveyed by the glass a a toward the object bb, by which means it will be strongly illuminated; and the rays d which flow from it, through the magnifying glass cc, will make a large inverted picture of the object at DD, which, being received on a white paper, will represent the object magnified in length, in proportion of the distance of the picture from the glass cc, to the distance of the object from the fame glass. Thus, suppose the distance of the object from the glass to be 3 parts of an inch, and the distance of the distinct picture to be 12 feet or 144 inches, in which there are 1440 tenths of an inch; and this number divided by 3 tenths, gives 480; which is the number of times the picture is longer or broader than the object; and the length multiplied by the breadth, shews how much the whole furface is magnified.

Before





Before we enter upon the description of tele-Telescopes. scopes, it will be proper to shew how the rays of light are affected by passing through concave glasses, and also by falling upon concave mirrors.

When parallel rays, as a b c d e f g b, pass Plate directly through a glass AB, which is equally XVIII. concave on both fides, they will diverge after passing through the glass, as if they had come from a radiant point C, in the center of the glass's concavity; which point is called the negative or virtual focus of the glass. Thus the ray a, after paffing through the glass AB, will go on in the direction k l, as if it had proceeded from the point C, and no glass been in the way. The ray b will go on in the direction mn; the ray c in the direction op, &c.—The ray C, that falls directly upon the middle of the glass, suffers no refraction in paffing through it; but goes on in the fame rectilineal direction, as if no glass had been in its way.

If the glass had been concave only on one side, and the other side quite plane, the rays would have diverged, after passing through it, as if they had come from a radiant point at double the distance of C from the glass; that is, as if the radiant had been at the distance of a whole dia-

meter of the glass's concavity.

If rays come more converging to such a glass, than parallel rays diverge after passing through it, they will continue to converge after passing through it; but will not meet so soon as if no glass had been in the way; and will incline toward the same side to which they would have diverged, if they had come parallel to the glass. Thus the rays f and b, going in a converging state toward the edge of the glass at B, and

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converging more in their way to it than the parallel rays diverge after passing through it, they will go on converging after they pass through it, though in a less degree than they did before, and will meet at 1: but if no glass had been in their

way, they would have met at i.

Fig. 2.

When the parallel rays, as d f a, Cmb, elc, fall upon a concave mirror AB (which is not transparent, but has only the furface A b B of a clear polish) they will be reflected back from that mirror, and meet in a point m, at half the distance of the surface of the mirror from C, the center of its concavity: for they will be reflected at as great an angle from the perpendicular to the surface of the mirror, as they fell upon it, with regard to that perpendicular; but on the other fide thereof. Thus, let C be the center of concavity of the mirror A b B, and let the parallel rays dfa, Cmb, and elc, fall upon it at the points a b, and c. Draw the lines Cia, Cmb, and Cbc, from the center C to these points; and all these lines will be perpendicular to the furface of the mirror, because they proceed thereto like fo many radii or spokes from its center. Make the angle Cab equal to the angle d a C, and draw the line a m b, which will be the direction of the ray d f a, after it is reflected from the point a of the mirror: fo that the angle of incidence da C, is equal to the angle of reflection Cab; the rays making equal angles with the perpendicular Cia on its oppofite fides.

Draw also the perpendicular Cbc to the point c, where the ray elc touches the mirror; and, having made the angle Cci, equal to the angle Cce, draw the line cmi, which will be the

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course of the ray elc, after it is reslected from the mirror.

The ray C m b passes through the center of concavity of the mirror, and falls upon it at b, the perpendicular to it; and is therefore reflected back from it in the same line b m C.

All these restected rays meet in the point m; and in that point the image of the body which emits the parallel rays da, Cb, and ec, will be formed: which point is distant from the mirror equal to half the radius b m C of its con-

cavity.

The rays which proceed from any celeftial object may be esteemed parallel at the earth; and therefore, the images of that object will be formed at m, when the reflecting surface of the concave mirror is turned directly toward the object. Hence, the socus m of parallel rays is not in the center of the mirror's concavity, but half way between the mirror and that center.

The rays which proceed from any remote terrestrial object, are nearly parallel at the mirror; not strictly fo, but come diverging to it, in separate pencils, or, as it were, bundles of rays, from each point of the fide of the object next the mirror: and therefore they will not be converged to a point, at the distance of half the radius of the mirror's concavity from its reflecting furface; but into separate points at a little greater distance from the mirror. And the nearer the object is to the mirror, the farther these points will be from it; and an inverted image of the object will be formed in them, which will feem to hang pendent in the air; and will be feen by an eye placed beyond it (with regard to the mirror) in all respects

like the object, and as distinct as the object itself.

Fig. 3.

Let AcB be the reflecting furface of a mirror, whose center of concavity is at C; and let the upright object DE be placed beyond the center C, and send out a conical pencil of diverging rays from its upper extremity D, to every point of the concave surface of the mirror AcB. But to avoid consustion, we only draw three rays of that pencil, as DA, Dc, DB.

From the center of concavity C, draw the three right lines CA, Cc, CB, touching the mirror in the same points where the foresaid rays touch it; and all these lines will be perpendicular to the furface of the mirror. Make the angle CAd equal to the angle DAC, and draw the right line Ad for the course of the reflected ray DA: make the angle Ccd equal to the angle D c C, and draw the right line cd for the course of the reflected ray Dd: make also the angle CBd equal to the angle DBC, and draw the right line B d for the course of the resected ray DB. All these reslected rays will meet in the point d, where they will form the extremity d of the inverted image ed, fimilar to the extremity D of the upright object DE.

If the pencils of rays Ef, Eg, Eb, be also continued to the mirror, and their angles of reflection from it be made equal to their angles of incidence upon it, as in the former pencil from D, they will all meet at the point e by reflection, and form the extremity e of the image ed, similar to the extremity E of the object DE.

And as each intermediate point of the object, between D and E, fends out a pencil of rays in like manner to every part of the mirror, the

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rays of each pencil will be reflected back from it, and meet in all the intermediate points between the extremities e and d of the image; and fo the whole image will be formed, not at i, half the distance of the mirror from its center of concavity C; but at a greater distance, between i and the object DE; and the image will be inverted with respect to the object.

This being well understood, the reader will easily see how the image is formed by the large concave mirror of the reflecting telescope, when he comes to the description of that instru-

ment.

When the object is more remote from the mirror than its center of concavity C, the image will be less than the object, and between the object and mirror: when the object is nearer than the center of concavity, the image will be more remote and bigger than the object: thus, if DE be the object, ed will be its image; for, as the object recedes from the mirror, the image approaches nearer to it; and as the object approaches nearer to the mirror, the image recedes farther from it; on account of the leffer or greater divergency of the pencils of rays which proceed from the object; for, the less they diverge, the fooner they are converged to points by reflection; and the more they diverge, the farther they must be reflected before they meet.

If the radius of the mirror's concavity and the distance of the object from it be known, the distance of the image from the mirror is found by this rule: divide the product of the distance and radius by double the distance made less by the radius, and the quotient is the dis-

tance required.

If the object be in the center of the mirror's concavity, the image and object will be coinci-

dent, and equal in bulk.

If a man places himself directly before a large concave mirror, but farther from it than its center of concavity, he will fee an inverted image of himfelf in the air, between him and the mirror, of a less size than himself. And if he holds out his hand toward the mirror, the hand of the image will come out toward his hand, and coincide with it, of an equal bulk, when his hand is in the center of concavity; and he will imagine he may shake hands with his image. If he reaches his hand farther, the hand of the image will pass by his hand, and come between his hand and his body: and if he moves his hand toward either fide, the hand of the image will move toward the other; fo that whatever way the object moves, the image will move the contrary way.

All the while a by-stander will see nothing of the image, because none of the reflected rays that

form it enter his eyes.

If a fire be made in a large room, and a fmooth mahogany table be placed at a good distance near the wall, before a large concave mirror, so placed, that the light of the fire may be reflected from the mirror to its focus upon the table; if a person stands by the table, he will see nothing upon it but a longish beam of light: but if he stands at a distance toward the fire, not directly between the fire and mirror, he will see an image of the fire upon the table, large and erect. And if another person, who knows nothing of this matter beforehand, should chance to come into the room, and should look from the fire toward the table,

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he would be flartled at the appearance; for the table would feem to be on fire, and by being near the wainfcot, to endanger the whole house. In this experiment there should be no light in the room, but what proceeds from the fire; and the mirror ought to be at least fifteen inches in diameter.

If the fire be darkened by a screen, and a large candle be placed at the back of the screen; a person standing by the candle will see the appearance of a fine large star, or rather planet, upon the table, as bright as Venus or Jupiter. And if a small wax taper (whose stame is much less than the stame of the candle) be placed near the candle, a satellite to the planet will appear on the table: and if the taper be moved round the candle, the satellite will go round the planet.

For these two pleasing experiments, I am indebted to the late reverend Dr. Long, Loundes's professor of astronomy at Cambridge, who savoured me with the sight of them, and many

more of his curious inventions.

In a refracting telescope, the glass which is nearest The rethe object in viewing it, is called the object-glass; fracting and that which is nearest the eye, is called the eye-glass. The object-glass must be convex, but the eye-glass may be either convex or concave: and generally, in looking through a telescope, the eye is in the focus of the eye-glass; though that is not very material: for the distance of the eye, as to distinct vision, is indifferent, provided the rays of the pencils fall upon it parallel: only the nearer the eye is to the end of the telescope, the larger is the scope or area of the field of view.

Let c d be a convex-glass fixed in a long tube, Fig. 4. and have its focus at E. Then, a pencil of rays Q g b i,

g b i, flowing from the upper extremity A of the remote object AB, will be so refracted by passing through the glass, as to converge and meet in the point f; while the pencil of rays klm flowing from the lower extremity B, of the same object AB, and passing through the glass, will converge and meet in the point e: and the images of the points A and B, will be formed in the points f and e. And as all the intermediate points of the object, between A and B, fend out pencils of rays in the fame manner, a fufficient number of these pencils will pass through the object glass & d, and converge to as many intermediate points between e and f; and fo will form the whole inverted image e E f, of the diffinct object. But because this image is small, a concave glass no is so placed in the end of the tube next the eye, that its virtual focus may be at F. And as the rays of the pencils pass converging through the concave glass, but converge less after paffing through it than before, they go on further, as to b and a, before they meet; and the pencils themselves being made to diverge by passing through the concave glass, they enter the eye, and form the large picture ab upon the retina, whereon it is magnified under the angle b Fa.

But this telescope has one inconveniency which renders it unfit for most purposes, which is, that the pencils of rays being made to diverge by passing through the concave glass no, very sew of them can enter the pupil of the eye; and therefore the field of view is but very small, as is evident by the signe. For none of the pencils which slow either from the top or bottom of the object AB can enter the pupil of the eye at C, but are all stopt by falling upon the iris above

above and below the pupil: and therefore, only the middle part of the object can be feen when the telescope lies directly toward it, by means of those rays which proceed from the middle of the object. So that to fee the whole of it, the telescope must be moved upward and downward, unless the object be very remote; and then it is

never feen distinctly.

This inconvenience is remedied by fubstitut- Fig. 5. ing a convex eye-glass, as g b, in place of the concave one; and fixing it so in the tube, that its focus may be coincident with the focus of the object-glass cd, as at E. For then, the rays of the pencils flowing from the object AB, and passing through the object-glass cd, will meet in its focus, and form the inverted image m E p: and as the image is formed in the focus of the eye-glass g b, the rays of each pencil will be parallel, after paffing through that glass; but the pencils themselves will cross in its focus, on the other side, as at e: and the pupil of the eye being in this focus, the image will be viewed through the glass, under the angle geb; and being at E, it will appear magnified, so as to fill the whole space Cmep D.

But, as this telescope inverts the image with respect to the object, it gives an unpleasant view of terrestrial objects; and is only fit for viewing the heavenly bodies, in which we regard not their position, because their being inverted does not appear, on account of their being round. whatever way the object feems to move, this telescope must be moved the contrary way, in order to keep fight of it; for, fince the object is in-

verted, its motion will be fo too.

The magnifying power of this telescope is, as the focal distance of the object-glass to the focal focal distance of the eye-glass. Therefore, if the former be divided by the latter, the quotient will

express the magnifying power.

When we speak of magnifying by a telescope or microscope, it is only meant with regard to the diameter, not to the area or folidity of the object, But as the instrument magnifies the vertical diameter, as much as it does the horizontal, it is eafy to find how much the whole visible area or furface is magnified: for, if the diameters be multiplied into one another, the product will express the magnification of the whole visible area, Thus, suppose the focal distance of the objectglass be ten times as great as the focal distance of the eye-glass; then, the object will be magnified ten times, both in length and breadth: and 10 multiplied by 10, produces 100; which shews, that the area of the object will appear 100 times as big when feen through fuch a telescope, as it does to the bare eye.

Hence it appears, that if the focal distance of the eye-glass, were equal to the focal distance of the object-glass, the magnifying power of the

telescope would be nothing.

This telescope may be made to magnify in any given degree, provided it be of a sufficient length. For, the greater the socal distance of the object-glass, the less may be the socal distance of the eye-glass; though not directly in proportion. Thus, an object-glass of 10 feet socal distance, will admit of an eye-glass whose socal distance is little more than 2½ inches; which will magnify near 48 times: but an object-glass, of 100 feet socus, will require an eye-glass somewhat more than 6 inches; and will therefore magnify almost 200 times.

th

A telescope for viewing terrestrial objects, should be so constructed, as to show them in their natural posture.

posture. And this is done by one object-glass Fig. 6. ed, and three eye-glaffes ef, gb, ik, fo placed, that the distance between any two, which are nearest to each other, may be equal to the sum of their focal distances; as in the figure, where the focus of the glasses cd and ef meet at F, those of the glasses e f and g b meet at l, and of g b and i k, at m; the eye being at n, in or near the focus of the eye-glass ik, on the other side. Then, it is plain, that these pencils of rays, which flow from the object AB, and pass through the object-glass cd, will meet and form an inverted image CFD in the focus of that glass; and the image being also in the focus of the glass ef, the rays of the pencils will become parallel, after passing through that glass, and cross at l, in the focus of the glass ef; from whence they pass on to the next glass g b, and by going through it they are converged to points in its other focus, where they form an erect image Em F, of the object AB: and as this image is also in the focus of the eye-glass ik, and the eye on the opposite side of the same glass; the image is viewed through the eye-glass in this telescope, in the fame manner as through the eye-glass in the former one; only in a contrary position, that is, in the fame position with the object.

The three glasses next the eye, have all their focal distances equal: and the magnifying power of this telescope is found the same way as that of the last above; viz. by dividing the focal distance of the object-glass cd, by the focal distance of the eye-glass ik, or gb, or ef, since all these

three are equal.

When the rays of light are feparated by refraction, they become coloured, and if they be united again, they will be a perfect white. But Q 3 those Why the those rays which pass through a convex glass, object ap-near its edges are more unequally refracted than pears co-those which are nearer the middle of the glass. Ioured, when seen And when the rays of any pencil are unequally through a refracted by the glass, they do not all meet telescope. again in one and the same point, but in separate

points; which makes the image indistinct, and coloured, about its edges. The remedy is, to have a plate with a small round hole in its middle, fixed in the tube at m, parallel to the glasses. For, the wandering rays about the edges of the glasses will be stopt, by the plate, from coming to the eye: and none admitted but those which come through the middle of the glass, or at least at a good distance from its edges, and pass through the hole in the middle of the plate. But this circumscribes the image, and lesses the field of view, which would be much larger if the plate could be dispensed with.

The reflecting telescope.

The great inconvenience attending the management of long telescopes of this kind, has brought them much into disuse ever fince the restering telescope was invented. For one of this sort, six seet in length, magnifies as much as one of the other an hundred seet. It was invented by Sir Isaac Newton, but has received considerable improvements since his time; and is now generally constructed in the following manner, which was first proposed by Dr. Gregory.

Fig. 7.

At the bottom of the great tube TTTT is placed the large concave mirror DUVF, whose principal focus is at m; and in its middle is a round hole P, opposite to which is placed the small mirror L, concave toward the great one; and so fixed to a strong wire M, that it may be moved farther from the great mirror, or nearer to it, by means of a long screw on the

out-

outside of the tube, keeping its axis still in the same line Pmn with that of the great one.—
Now, since in viewing a very remote object, we can scarce see a point of it but what is at least as broad as the great mirror, we may consider the rays of each pencil, which slow from every point of the object, to be parallel to each other, and to cover the whole reflecting surface DUVF. But to avoid consusion in the figure, we shall only draw two rays of a pencil flowing from each extremity of the object into the great tube, and trace their progress, through all their reflections and refractions, to the eye f, at the end of the small tube tt, which is joined to the great one.

Let us then suppose the object AB to be at fuch a distance, that the rays & may slow from its lower extremity B, and the rays E from its upper extremity A. Then the rays C falling parallel upon the great mirror at D, will be thence reflected, converging in the direction DG; and by croffing at I in the principal focus of the mirror, they will form the upper extremity I of the inverted image IK, fimilar to the lower extremity B of the object AB: and paffing on to the concave mirror L (whose focus is at n) they will fall upon it at g, and be thence reflected converging in the direction g N, because gm is longer than gm; and passing through the hole P in the large mirror, they would meet fomewhere about r, and form the lower extremity b of the erect image ab, fimilar to the lower extremity B of the object AB. But by passing through the plano-convex glass R in their way, they form that extremity of the image at b. In like manner, the rays E, which come from the top of the object AB, and fall parallel upon the great mirror at F, are thence reflected converg-

ing

ing to its focus, where they form the lower extremity K of the inverted image IK, fimilar to the upper extremity A of the object AB; and thence paffing on to the small mirror L, and falling upon it at b, they are thence reflected in the converging state bO; and going on through the hole P of the great mirror, they will meet fomewhere about q, and form there the upper extremity a of the erect image ab, similar to the upper extremity A of the object AB: but by passing through the convex glass R in their way, they meet and cross sooner, as at a, where that point of the erect image is formed.—The like being understood of all those rays which flow from the intermediate points of the object, between A and B, and enter the tube TT; all the intermediate points of the image between a and b will be formed: and the rays passing on from the image through the eye glass S, and through a small hole e in the end of the lesser tube tt, they enter the eye f, which fees the image ab (by means of the eye-glass) under the large angle ced, and magnified in length, under that angle from c to d.

In the best restecting telescopes, the socus of the small mirror is never coincident with the socus m of the great one, where the first image IK is formed, but a little beyond it (with respect to the eye) as at n: the consequence of which is, that the rays of the pencils will not be parallel after reslection from the small mirror, but converge so as to meet in points about q, e, r; where they will form a larger upright image than ab, if the glass R was not in their way; and this image might be viewed by means of a single eye-glass properly placed between the image and the eye: but then the field of view would be

less, and consequently not so pleasant; for which reason, the glass R is still retained, to enlarge the

scope or area of the field.

To find the magnifying power of this telefcope, multiply the focal diffance of the great mirror by the diffance of the fmall mirror from the image next the eye, and multiply the focal diffance of the fmall mirror by the focal diffance of the eye-glafs; then, divide the product of the former multiplication by the product of the latter, and the quotient will express the magnifying power.

I shall here set down the dimensions of one of Mr. Short's reflecting telescopes, as described in

Dr. Smith's Optics.

The focal distance of the great mirror 9.6 inches, its breadth 2.3; the focal distance of the small mirror 1.5, its breadth 0.6; the breadth of the hole in the great mirror 0.5; the distance between the small mirror and the next eye-glass 14.2; the distance between the two eye-glasses 2.4; the focal distance of the eye-glass next the metals 3.8; and the focal distance of the eye-glass next the eye 1.1.

One great advantage of the reflecting telefcope is, that it will admit of an eye-glass of a much shorter focal distance than a refracting telescope will; and, consequently, it will magnify so much the more; for the rays are not coloured by reflection from a concave mirror, if it be ground to a true figure, as they are by passing through a convex-glass, let it be ground ever so

true.

The adjusting screw on the outside of the great tube sits this telescope to all sorts of eyes, by bringing the small mirror either nearer to the eye, or removing it farther; by which means,

means, the rays are made to diverge a little for short-sighted eyes, or to converge for those of a

long fight.

The nearer an object is to the telescope, the more its pencils of rays will diverge before they fall upon the great mirror, and therefore they will be the longer of meeting in points after reflection; fo that the first image IK will be formed at a greater distance from the large mirror, when the object is near the telescope, than when it is very remote. But as this image must be formed farther from the small mirror than its principal focus n, this mirror must be always set at a greater distance from the large one, in viewing near objects, than in viewing remote ones. And this is done by turning the screw on the outfide of the tube, until the small mirror be so adjusted, that the object (or rather its image) appears perfect.

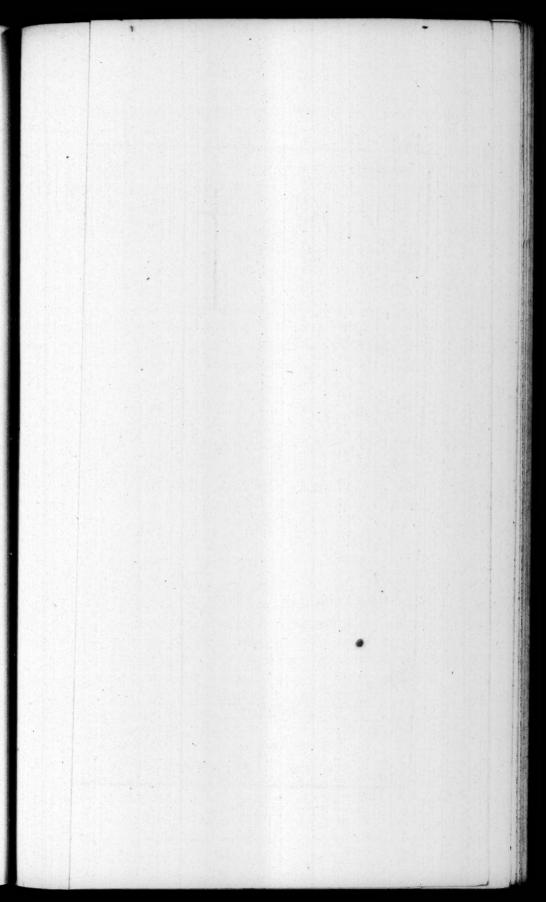
object, we never fee the object itself, but only that image of it which is formed next the eye in the telescope. For, if a man holds his finger or a stick between his bare eye and an object, it will hide part (if not the whole) of the object from his view. But if he ties a stick across the mouth of a telescope, before the object-glass, it will hide no part of the imaginary object he saw through the telescope before, unless it covers the whole mouth of the tube: for, all the effect will be, to make the object appear dimmer, because it intercepts part of the rays. Whereas, if he puts only a piece of wire across the inside of the tube,

In looking through any telescope toward an

part of the object which he thinks he fees: which proves that he fees not the real object, but its image. This is also confirmed by means of the

between the eye-glass and his eye, it will hide

fmall



small mirror L, in the reflecting telescope, which is made of opaque metal, and stands directly between the eye and the object toward which the telescope is turned; and will hide the whole object from the eye at e, if the two glasses R and S are taken out of the tube.

The multiplying glass is made by grinding Plate down the round fide bik of a convex glass ABXIX. into several flat surfaces, as bb, bld, dk. An The mulobject C will not appear magnified, when feen tiplying through this glass, by the eye at H; but it will glass. appear multiplied into as many different objects as the glass contains plane surfaces. For, since rays will flow from the object C to all parts of the glass, and each plane surface will refract these rays to the eye, the same object will appear to the eye, in the direction of the rays which enter it through each furface. Thus, a ray g i H, falling perpendicularly on the middle furface. will go through the glass to the eye without suffering any refraction; and will therefore shew the object in its true place at C: while a ray ab flowing from the same object, and falling obliquely on the plane furface bb, will be refracted in the direction be, by passing through the glass; and upon leaving it, will go on to the eye in the direction eH; which will cause the same object C to appear also at E, in the direction of the ray He, produced in the right line Hen. And the ray cd, flowing from the object C, and falling obliquely on the plane furface dk, will be refracted (by passing through the glass and leaving it at f) to the eye at H; which will cause the same object to appear at D, in the direction Hfm.— If the glass be turned round the line glH, as an axis, the object C will keep its place, because the furface bld is not removed; but all the other

other objects will feem to go round C, because the oblique planes, on which the rays ab, cd fall, will go round by the turning of the glass.

Fig. 2. The camera of scura is made by a convex glass. The came- CD, placed in a hole of a window-shutter. Then, if the room be darkened so as no light can enter but what comes through the glass, the pictures of all the objects (as fields, trees, buildings, men, cattle, &c.) on the outside, will be shewn in an inverted order, on a white paper placed at GH in the socus of the glass; and will afford a most beautiful and perfect piece of perspective or landscape of whatever is before

objects.

If the convex glass CD be placed in a tube in the fide of a square box, within which is the plane mirror EF, reclining backward in an angle of 45 degrees from the perpendicular kq, the pencils of rays flowing from the outward objects, and paffing through the convex glass to the plane mirror, will be reflected upward from it, and meet in points, as I and K (at the same distance that they would have met at H and G, if the mirror had not been in the way) and will form the aforefaid images on an oiled paper stretched horizontally in the direction IK; on which paper, the outlines of the images may be eafily drawn with a black lead pencil; and then copied on a clean sheet, and coloured by art, as the objects themselves are by nature.-In this machine, it is usual to place a plane glass, unpolished, in the horizontal fituation 1 K, which glass receives the images of the outward objects; and their oudines may be traced upon it by a black lead pencil. N. B.

the glass; especially if the sun shines upon the

N. B. The tube in which the convex glass CD is fixed, must be made to draw out, or push in, so as to adjust the distance of that glass from the plane mirror, in proportion to the distance of the outward objects; which the operator does, until he sees their images distinctly painted on

the horizontal glass at IK.

The forming a horizontal image, as IK, of an upright object, AB, depends upon the angles of incidence of the rays upon the plane mirror EF, being equal to their angles of reflection from it. For, if a perpendicular be supposed to be drawn to the furface of the plane mirror at e, where the ray Aa Ce falls upon it, that ray will be reflected upward in an equal angle with the other side of the perpendicular, in the line ed I. Again, if a perpendicular be drawn to the mirror from the point f, where the ray Abf falls upon it, that ray will be reflected in an equal angle from the other fide of the perpendicular, in the line f b I. And if a perpendicular be drawn from the point g, where the ray Acg falls upon the mirror, that ray will be reflected in an equal angle from the other fide of the perpendicular, in the line gi I. So that all the rays of the pencil abc, flowing from the upper extremity of the object AB, and passing through the convex glass CD, to the plane mirror EF, will be reflected from the mirror and meet at I, where they will form the extremity I of the image IK, fimilar to the extremity A of the object AB. like is to be understood of the pencil qrs, flowing from the lower extremity of the object AB, and meeting at K (after reflection from the plane mirror) the rays form the extremity K of the image, fimilar to the extremity B of the object: and so of all the pencils that flow from the intermediate

termediate points of the object to the mirror.

through the convex glass.

The operaglass.

If a convex glass, of a short focal distance, be placed near the plane mirror, in the end of a short tube, and a convex glass be placed in a hole in the fide of the tube, fo as the image may be formed between the last-mentioned convex glass, and the plane mirror, the image being viewed through this glass will appear magnified. -In this manner the opera-glaffes are constructed; with which a gentleman may look at any lady at a distance in the company, and the lady know nothing of it.

The common looking-glass.

The image of any object that is placed before a plane mirror, appears as big to the eye as the object itself; and is erect, distinct, and feemingly as far behind the mirror, as the object is before it: and that part of the mirror, which reflects the image of the object to the eye (the eye being supposed equally distant from the glass with the object) is just half as long and half as broad as the object itself. Let AB be an object placed before the reflecting furface g bi of the plane mirror CD; and let the eye be at o. Let Ab be a ray of light flowing from the top A of the object, and falling upon the mirror at b: and bm be a perpendicular to the furface of the mirror at b, the ray Ab will be reflected from the mirror to the eye at o, making an angle m b o equal to the angle Abm: then will the top of the image E appear to the eye in the direction of the reflected ray ob produced to E, where the right line A p E, from the top of the object, cuts the right line ob E, at E. Let Bi be a ray of light proceeding from the foot of the object at B to the mirror at i, and ni a perpendicular to the mirror from the point i, where

Fig. 3.

where the ray Bi falls upon it: this ray will be reflected in the line io, making an angle nio, equal to the angle Bin, with that perpendicular, and entering the eye at o: then will the foot F of the image appear in the direction of the reflected ray oi, produced to F, where the right line BF cuts the reflected ray produced to F. All the other rays that flow from the intermediate points of the object AB, and fall upon the mirror between b and i, will be reflected to the eye at o; and all the intermediate points of the image EF will appear to the eye in the direction-line of these reflected rays produced. But all the rays that flow from the object, and fall upon the mirror above b, will be reflected back above the eye at o; and all the rays that flow from the object, and fall upon the mirror below i, will be reflected back below the eye at o: fo that none of the rays that fall above b, or below i, can be reflected to the eye at o; and the distance between b and i is equal to half the length of the object AB.

Hence it appears, that if a man fee his whole A man image in a plane looking-glass, the part of the will see glass that reflects his image must be just half as his image in a plane long and half as broad as himfelf, let him stand lookingat any distance from it whatever; and that his glass, that image must appear just as far behind the glass as is but half he is before it. Thus, the man AB viewing Fig. 4. himself in the plane mirror CD, which is just half as long as himfelf, fees his whole image as at EF, behind the glass, exactly equal to his own fize. For, a ray AC proceeding from his eye at A, and falling perpendicularly upon the furface of the glass at C, is reflected back to his eye in the fame line CA; and the eye of his image will appear at E, in the fame line pro-

duced

duced to E, beyond the glass. And a ray  $BD_A$  flowing from his foot, and falling obliquely on the glass at D, will be reflected as obliquely on the other fide of the perpendicular a b D, in the direction DA; and the foot of his image will appear at F, in the direction of the reflected ray AD, produced to F, where it is cut by the right line BGF, drawn parallel to the right line ACE. Just the same as if the glass were taken away, and a real man stood at F, equal in size to the man standing at B: for to his eye at A, the eye of the other man at E would be seen in the direction of the line ACE; and the foot of the man at F would be seen by the eye A, in the direction of the line ADF.

If the glass be brought nearer the man AB, as suppose to cb, he will see his image as at CDG: for the reflected ray CA (being perpendicular to the glass) will shew the eye of the image as at C; and the incident ray Bb, being reflected in the line bA, will shew the foot of his image as at G; the angle of reflection abA being always equal to the angle of incidence Bba: and so of all the intermediate rays from A to Ba. Hence, if the man AB advances toward the glass CD, his image will approach toward it; and if he recedes from the glass, his image will also recede from it.

Having already shewn, that the rays of light are refracted when they pass obliquely through different mediums, we come now to prove that some rays are more refrangible than others; and that, as they are differently refracted, they excite in our minds the ideas of different colours. This will account for the colours seen about the edges of the images of those objects which are viewed

through fome telescopes:

Let the fun shine into a dark room through a Fig. 5. small hole, as at e e, in a window-shutter; and place a triangular prism BC in the beam of rays A, in such a manner, that the beam may fall obliquely on one of the fides a b C of the prism. The rays will fuffer different refractions by paffing through the prism, so that instead of going all The out of it on the fide d c C, in one direction, they prifm. will go on from it in the different directions represented by the lines f, g, h, i, k, l, m, n; and falling upon the opposite side of the room, or on white paper placed as at pq to receive them, they will paint upon it a feries of most beautiful lively colours (not to be equalled by art) in this The coorder, viz. those rays which are least refracted by lours of, the prism, and will therefore go on between the lines n and m, will be of a very bright intense red at n, degenerating from thence gradually into an orange colour, as they are nearer the line m: the next will be of a fine orange colour at m, and from thence degenerate into a yellow colour toward 1: at 1 they will be of a fine vellow, which will incline toward a green, more and more, as they are nearer and nearer k: at k they will be a pure green, but from thence toward i they will incline gradually to a blue: at i they will be a perfect blue, inclining to an indigo colour from thence toward b: at b they will be quite the colour of indigo, which will gradually change toward a violet, the nearer they are to g: and at g they will be of a fine violet colour, which will incline gradually to a red as they come nearer to f, where the coloured image ends.

There is not an equal quantity of rays in each of these colours; for if the oblong image  $p \neq q$  be divided into 360 equal parts, the red space

R will take up 45 of these parts; the orange  $O_y$  27; the yellow Y, 48; the green G, 60; the blue B, 60; the indigo I, 40; and the violet V, 80; all which spaces are as nearly proportioned in the figure as the small space pq would admit of.

If all these colours be blended together again, they will make a pure white; as is proved thus. Take away the paper on which the colours pq fell, and place a large convex glass D in the rays f, g, b, &c. which will refract them so, as to make them unite and cross each other at W; where, if a white paper be placed to receive them, they will excite the idea of a strong lively white. But if the paper be placed farther from the glass, as at rs, the different colours will appear again upon it, in an inverted order, occasioned by the rays crossing at W.

As white is a composition of all colours, so black is a privation of them all, and, therefore,

properly no colour.

Fig. 6.

Let two concentric circles be drawn on a fmooth round board A B C D E F G, and the outermost of them divided into 360 equal parts or degrees: then, draw feven right lines, as O A, O B, &c. from the center to the outermost circle; making the lines  $\odot$  A and  $\odot$  B include 80 degrees of that circle; the lines O B and O C 40 degrees; O C and O D 60; O D and O E 60; O E and O F 48; O F and O G 27; O G and O A Then, between these two circles, paint the fpace A G red, inclining to orange near G; GF orange, inclining to yellow near F; F E yellow, inclining to green near E; E D green, inclining to blue near D; DC blue, inclining to indigo near C; CB indigo, inclining to violet near B; and B A violet, inclining to a foft red near A. This done, paint all that part of the board black which

which lies within the inner circle; and putting All the an axis through the center of the board, let it prismatic be turned very swiftly round that axis, so as the colours rays proceeding from the above colours, may be together, all blended and mixed together in coming to make a the eye; and then, the whole coloured part will white. appear like a white ring, a little greyish; not perfectly white, because no colours prepared by art are perfect.

Any of these colours, except red and violet, may be made by mixing together the two contiguous prismatic colours. Thus, yellow is made by mixing together a due proportion of orange and green; and green may be made by a mix-

ture of yellow and blue.

All bodies appear of that colour, whose rays they reflect most; as a body appears red when it reflects most of the red-making rays, and abforbs the rest.

Any two or more colours that are quite tranf- Transpaparent by themselves, become opaque when put rent cotogether. Thus, if water or spirits of wine be come tinged red, and put in a phial, every object feen opaque, through it will appear red; because it lets only if put tothe red rays pass through it, and stops all the gether. rest. If water or spirits be tinged blue, and put in a phial, all objects feen through it will appear blue, because it transmits only the blue rays, and stops all the rest. But if these two phials are held close together, so as both of them may be between the eye and object, the object will no more be feen through them than through a plate of metal; for whatever rays are transmitted through the fluid in the phial next the object, are stopped by that in the phial next the eye. In this experiment, the phials ought not to be round, but square; because nothing but the light

ight itself can be seen through a round transpa-

rent body, at any distance.

As the rays of light fuffer different degrees of refraction by passing obliquely through a prism, or through a convex glass, and are thereby separated into all the seven original or primary colours; so they also suffer different degrees of refraction by passing through drops of falling rain; and then, being reslected toward the eye, from the sides of these drops which are farthest from the eye, and again refracted by passing out of these drops into the air, in which refracted directions they come to the eye; they make all the colours to appear in the form of a fine arch in the heavens, which is called the rain-bow.

There are always two rain-bows feen together, the interior of which is formed by the rays a b, which falling upon the upper part b, of the drop b c d, are refracted into the line b c as they enter the drop, and are reflected from the back of it at c, in the line c d, and then, by passing out of the drop into air, they are again-refracted at d; and from thence they pass on to the eye at e: so that to form the interior bow, the rays suffer two refractions, as at b and d; and one reflection, as at c.

The exterior bow is formed by rays which fuffer two reflections, and two refractions; which is the occasion of its being less vivid than the interior, and also of its colours being inverted with respect to those of the interior. For, when a ray a b falls upon the lower part of the drop b c d e, it is refracted into the direction b c by entering the drop; and passing on to the back of the drop at c, it is thence reslected in the line c d, in which direction it is impossible for it to enter the eye at f: but by being again re-

flected

Fig. 7.

Fig. 8.

flected from the point d of the drop, it goes on in the drop to e, where it passes out of the drop into the air, and is there refracted downward to the eye, in the direction e f.

# LECT. VIII. AND IX.

The description and use of the globes, and armillary sphere.

I F a map of the world be accurately delineated The teron a spherical ball, the surface thereof will restrict
represent the surface of the earth; for the highest
hills are so inconsiderable with respect to the bulk
of the earth, that they take off no more from its
roundness, than grains of sand do from the roundness of a common globe; for the diameter of
the earth is 8000 miles in round numbers, and
no known hill upon it is three miles in perpendicular height.

That the earth is spherical, or round like a Proof of globe, appears, 1. From its casting a round the shadow upon the moon, whatever side be turned earth's being toward her when she is eclipsed. 2. From its globular, having been sailed round by several persons.

3. From our seeing the farther, the higher we stand. 4. From our seeing the masts of a ship, while the hull is hid by the convexity of the water.

The attractive power of the earth draws all it may be terrestrial bodies toward its center; as is evi-peopled dent from the descent of bodies in lines perpendicular to the earth's surface, at the places any one's whereon they fall; even when they are thrown being in off from the earth on opposite sides, and confequently, in opposite directions. So that the way from R 3 earth it.

earth may be compared to a great magnet rolled in filings of steel, which attracts and keeps them equally fast to its surface on all sides. Hence, as all terrestrial bodies are attracted toward the earth's center, they can be in no danger of falling from any fide of the earth, more than from

any other.

Up and down, what.

The heaven or fky furrounds the whole earth: and when we speak of up or down, we mean only with regard to ourselves; for no point, either in the heaven, or on the furface of the earth, is above or below, but only with respect to ourselves. And let us be upon what part of the earth we will, we stand with our feet toward its center, and our heads toward the sky: and so we say, it is up toward the sky, and down toward the center of the earth.

All objects in the heaven appear equally distant.

To an observer placed any where in the indefinite space, where there is nothing to limit his view, all remote objects appear equally distant from him; and feem to be placed in a vast concave sphere, of which his eye is the Every aftronomer can demonstrate, center. that the moon is much nearer to us than the fun is; that fome of the planets are fometimes nearer to us, and fometimes farther from us, than the fun; that others of them never come for near us as the fun always is; that the remotest planet in our system, is beyond comparison nearer to us than any of the fixed stars are; and that it is highly probable fome flars are, in a manner, infinitely more diffant from us than others; and yet all these celestial objects appear equally distant from us. Therefore, if we imagine a large hollow sphere of glass to have as many bright studs fixed to its inside, as and earth there are stars visible in the heaven, and these

The face of the heaven

fluds

At the fame angular distances from each other ed in a as the stars are; the sphere will be a true representation of the starry heaven, to an eye supposed to be in its center, and viewing it all around. And if a small globe, with a map of the earth upon it, be placed on an axis in the center of this starry sphere, and the sphere be made to turn round on this axis, it will represent the apparent motion of the heavens round the earth.

If a great circle be so drawn upon this sphere, as to divide it into two equal parts, or hemispheres, and the plane of the circle be perpendicular to the axis of the sphere, this circle will represent the equinoctial, which divides the hea-The equiven into two equal parts, called the northern and noctial. the southern hemispheres; and every point of that circle will be equally distant from the poles, or The poles. ends of the axis in the sphere. That pole which is in the middle of the northern hemisphere, will be called the north pole of the sphere, and that which is in the middle of the southern hemisphere, the south pole.

If another great circle be drawn upon the sphere, in such a manner as to cut the equinoctial at an angle of  $23\frac{1}{4}$  degrees in two opposite points, it will represent the ecliptic, or circle of The eclipthe sun's apparent annual motion; one half of the which is on the north side of the equinoctial, and the other half on the south.

If a large stud be made to move eastward in this ecliptic, in such a manner as to go quite round it, in the time that the sphere is turned round westward 366 times upon its axis; this stud will represent the sun, changing his place The sun. every day a 365th part of the ecliptic; and R 4 going

going round westward, the same way as the stars do; but with a motion so much slower than the motion of the stars, that they will make 366 revolutions about the axis of the sphere, in the time that the sun makes only 365. During one half of these revolutions, the sun will be on the north side of the equinoctial; during the other half, on the south; and at the end of each half, in the equinoctial.

The earth.

The apparent motion of the heavens.

If we suppose the terrestrial globe in this machine to be about one inch in diameter, and the diameter of the starry sphere to be about five or fix feet, a fmall infect on the globe would fee only a very little portion of its furface; but it would fee one half of the ftarry fphere; the convexity of the globe hiding the other half from its view. If the sphere be turned westward round the globe, and the infect could judge of the appearances which arife from that motion, it would fee some stars rising to its view in the eastern fide of the sphere, while others were setting on the western: but as all the stars are fixed to the fphere, the fame ftars would always rife in the fame points of view on the east side, and set in the same points of view on the west side. With the fun it would be otherwise, because the sun is not fixed to any point of the sphere, but moves flowly along an oblique circle in it. if the infect should look toward the fouth, and call that point of the globe, where the equinoctial in the sphere seems to cut it on the left fide, the east point; and where it cuts the globe on the right fide, the west point; the little animal would fee the fun rife north of the east, and fet north of the west, for 1821 revolutions; after which, for as many more, the fun would rife fouth of the east, and set south of the west.

west. And in the whole 365 revolutions, the sun would rise only twice in the east point, and set twice in the west. All these appearances would be the same, if the starry sphere stood still (the sun only moving in the ecliptic) and the earthly globe were turned round the axis of the sphere eastward. For, as the insect would be carried round with the globe, he would be quite insensible of its motion; and the sun and stars would

appear to move westward.

We are but very small beings when compared with our earthly globe, and the globe itself is but a dimentionless point compared with the magnitude of the starry heavens. Whether the earth be at rest, and the heaven turns round it, or the heaven be at rest, and the earth turns round, the appearance to us will be exactly the same. And because the heaven is so immensely large, in comparison of the earth, we see one half of the heaven as well from the earth's surface, as we could do from its center, if the limits of our view are not intercepted by hills.

We may imagine as many circles described Circles of upon the earth as we please; and we may ima-the spheres gine the plane of any circle described upon the earth to be continued, until it marks a circle in

the concave fphere of the heavens.

The borizon is either fensible or rational. The The hofensible horizon is that circle, which a man stand-rizon.
ing upon a large plane, observes to terminate his
view all around, where the heaven and earth seem
to meet. The plane of our sensible horizon continued to the heaven, divides it into two hemispheres; one visible to us, the other hid by the
convexity of the earth.

The

Poles.

The plane of the rational horizon, is supposed parallel to the plane of the sensible; to pass through the center of the earth, and to be continued to the heavens. And although the plane of the sensible horizon touches the earth in the place of the observer, yet this plane, and that of the rational horizon, will seem to coincide in the heaven, because the whole earth is but a point compared to the sphere of the heaven.

The earth being a fpherical body, the horizon, or limit of our view, must change as we change

our place.

The poles of the earth, are those two points on its surface in which its axis terminates. The one is called the north pole, and the other the south pole.

The poles of the heaven, are those two points in which the earth's axis produced terminates in the heaven: so that the north pole of the heaven is directly over the north pole of the earth; and the fouth pole of the heaven is directly over the south pole of the earth.

Equator.

The equator is a great circle upon the earth, every part of which is equally distant from either of the poles. It divides the earth into two equal parts, called the northern and fouthern bemispheres. If we suppose the plane of this circle to be extended to the heaven, it will mark the equinostial therein, and will divide the heaven into two equal parts, called the northern and fouthern hemispheres of the heaven.

Meridian.

The meridian of any place is a great circle passing through that place and the poles of the earth. We may imagine as many such meridians as we please, because any place that is

ever

ever so little to the east or west of any other place, has a different meridian from that place; for no one circle can pass through any two such places

and the poles of the earth.

The meridian of any place is divided by the poles, into two femicircles: that which paffes through the place is called the geographical or upper meridian; and that which passes through the opposite place; is called the lower meridian.

When the rotation of the earth brings the Noon and plane of the geographical meridian to the fun, mid-night. it is noon or mid-day to that place; and when our lower meridian comes to the fun, it is mid-

night.

All places lying under the fame geographical meridian, have their noon at the fame time, and confequently all the other hours. All those places are faid to have the fame longitude, because no one of them lies either eastward or westward

from any of the rest.

If we imagine 24 femicircles, one of which is Hour cirthe geographical meridian of a given place, to cles. meet at the poles, and to divide the equator into 24 equal parts; each of these meridians will come round to the fun in 24 hours, by the earth's equable motion round its axis in that time. And. as the equator contains 360 degrees, there will be 15 degrees contained between any two of these meridians which are nearest to one another: for 24 times 15 is 360. And as the earth's motion is eastward, the sun's apparent motion will be westward, at the rate of 15 degrees each hour. Therefore,

They whose geographical meridian is 15 de-Longitude. grees eastward from us, have noon, and every other hour, a hour fooner than we have. whose meridian is fifteen degrees westward from

Ecliptic.

us, have noon, and every other hour, a hour later than we have: and fo on in proportion, reckoning one hour for every fifteen degrees.

As the earth turns round its axis once in 24

hours, and shews itself all round to the fun in that time; fo it goes round the fun once a year, in a great circle called the ecliptic, which croffes the equinoctial in two-opposite points, making an angle of 231 degrees with the equinoctial on each fide. So that one half of the ecliptic is in the northern hemisphere, and the other in the fouthern. It contains 360 equal parts, called degrees (as all other circles do, whether great or fmall) and as the earth goes once round it every year, the fun will appear to do the fame, changing his place almost a degree, at a mean rate, every 24 hours. So that whatever place, or degree of the ecliptic, the 'earth is in at any time, the fun will then appear in the opposite. And as one half of the ecliptic is on the north fide of the equinoctial, and the other half on the fouth; the fun, as feen from the earth, will be half a year on the fouth fide of the equinoctial,

Signs and degrees.

in the equinoctial itself.

The ecliptic is divided by astronomers into 12 equal parts, called figns, each sign into 30 degrees, and each degree into 60 minutes: but in using the globes, we seldom want the sun's place nearer

and half a year on the north; and twice a year

than half a degree of the truth.

The names and characters of the 12 figns are as follow; beginning at that point of the ecliptic where it crosses the equinoctial to the northward, and reckoning eastward round to the same point again. And the days of the months on which the sun now enters the signs, are set down below them.

Aries,

Aries,	Taurus,	Gemini,	.Cancer,
n	8	II .	ত্ত
March	April	May	June
20	19	20	21
Leo,	Virgo,	Libra,	Scorpio,
N	m	_	m
July	August	September	October
22	22	22	22 .
Sagittari	us, Capricon	rnus, Aqueri	us, Pisces,
1	B		×
Novemb	per Decem	ber Januar	y February
21	21	(0)	18

By remembering on what day the fun enters any particular fign, we may eafily find his place any day afterward, while he is in that fign, by reckoning a degree for each day; which will occasion no error of consequence in using the

globes.

When the sun is at the beginning of Aries, he is in the equinoctial; and from that time he declines northward every day, until he comes to the beginning of Cancer, which is  $23\frac{1}{2}$  degrees from the equinoctial; from thence he recedes southward every day, for half a year; in the middle of which half, he crosses the equinoctial at the beginning of Libra, and at the end of that half year, he is at his greatest fouth declination, in the beginning of Capricorn, which is also  $23\frac{1}{2}$  degrees from the equinoctial. Then, he returns northward from Capricorn every day, for half a year; in the middle of which half, he crosses the equinoctial at the beginning of Aries; and at the end of it he arrives at Cancer.

The sun's motion in the ecliptic is not perfectly equable, for he continues eight days longer in the northern half of the ecliptic, than in the southern: so that the summer half year, in the northern hemisphere, is eight days longer than the winter half year; and the contrary in the southern hemisphere.

Tropics.

The tropics are lesser circles in the heaven, parallel to the equinoctial; one on each side of it, touching the ecliptic in the points of its greatest declination; so that each tropic is 23½ degrees from the equinoctial, one on the north side of it, and the other on the south. The northern tropic touches the ecliptic at the beginning of Cancer, the southern at the beginning of Capricorn; for which reason the former is called the tropic of Cancer, and the latter the tropic of Capricorn.

Polar circles.

The polar circles in the heaven, are each 23½ degrees from the poles, all around. That which goes round the north pole, is called the artic circle, from apriles, which fignifies a bear; there being a collection or groupe of stars near the north pole, which goes by that name. The fouth polar circle, is called the antartic circle, from its

being opposite to the arctic.

The ecliptic, tropics, and polar circles, are drawn upon the terrestrial globe, as well as upon the celestial. But the ecliptic, being a great fixed circle in the heavens, cannot properly be said to belong to the terrestrial globe; and is laid down upon it only for the conveniency of solving some problems. So that, if this circle on the terrestrial globe was properly divided into the months and days of the year, it would not only suit the globe better, but would also make the problems thereon much easier.

In

In order to form a true idea of the earth's motion round its axis every 24 hours, which is the cause of day and night; and of its motion in the ecliptic round the sun every year, which is the cause of the different lengths of days and nights, and of the vicissitude of seasons; take the following method, which will be both easy and pleasant.

Let a small terrestrial globe, of about three An idea inches diameter, be suspended by a long thread of the of twisted filk, fixt to its north pole: then hav-feafons. ing placed a lighted candle on a table, to reprefent the fun, in the center of a hoop of a large cask, which may represent the ecliptic, the hoop making an angle of 231 degrees with the plane of the table; hang the globe within the hoop near to it; and if the table be level, the equator of the globe will be parallel to the table, and the plane of the hoop will cut the equator at an angle of 231 degrees: fo that one half of the equator will be above the hoop, and the other half below it; and the candle will enlighten one half of the globe, as the fun enlightens one half of the earth, while the other half is in the dark.

Things being thus prepared, twist the thread toward the left hand, that it may turn the globe the same way by untwisting; that is, from west, by south, to east. As the globe turns round its axis or thread, the different places of its surface will go regularly through the light and dark; and have, as it were, an alternate return of day and night in each rotation. As the globe continues to turn round, and to shew itself all around to the candle, carry it slowly round the hoop by the thread, from west, by south, to east; which is the way that the earth

moves

moves round the fun, once a year, in the ecliptic: and you will fee, that while the globe continues in the lower part of the hoop, the candle (being then north of the equator) will conflantly shine round the north pole; and all the northern places which go through any part of the dark, will go through a less portion of it than they do of the light; and the more fo, the farther they are from the equator; consequently, their days are then longer than their nights. When the globe comes to a point in the hoop, mid-way between the highest and lowest points, the candle will be directly over the equator, and will enlighten the globe just from pole to pole; and then every place on the globe will go through equal portions of light and darkness. as it runs round its axis; and confequently, the day and night will be of equal length at all places upon it. As the globe advances thenceforward, toward the highest part of the hoop, the candle will be on the fouth fide of the equator, shining farther and farther round the fouth pole, as the globe rifes higher and higher in the hoop; leaving the north pole as much in darknefs, as the fouth pole is then in the light, and making long days and short nights on the fouth fide of the equator, and the contrary on the north fide, while the globe continues in the northern or higher fide of the hoop: and when it comes to the highest point, the days will be at the longest, and the nights at the shortest, in the fouthern hemisphere; and the reverse in the northern. As the globe advances and defcends in the hoop, the light will gradually recede from the fouth pole, and approach toward the north pole, which will cause the northern days to lengthen, and the fouthern days to shorten in the

the same proportion. When the globe comes to the middle point, between the highest and lowest points of the hoop, the candle will be over the equator, enlightening the globe just from pole to pole, when every place of the earth (except the poles) will go through equal portions of light and darkness; and consequently, the day and night will be then equal, all over the globe.

And thus, at a very small expence, one may have a delightful and demonstrative view of the cause of days and nights, with their gradual increase and decrease in length, through the whole year together, with the vicissitudes of spring, summer, autumn, and winter, in each annual

course of the earth round the fun.

If the hoop be divided into 12 equal parts, and the figns be marked in order upon it, beginning with Cancer at the highest point of the hoop, and reckoning eastward (or contrary to the apparent motion of the fun) you will fee how the fun appears to change his place every day in the ecliptic, as the globe advances eastward along the hoop, and turns round its own axis: and that when the earth is in a low fign, as at Capricorn, the fun must appear in a high fign, as at Cancer, opposite to the earth's real place: and that while the earth is in the fouthern half of the ecliptic, the fun appears in the northern half, and vice versa: that the farther any place is from the equator, between it and the polar circle, the greater is the difference between the longest and shortest day at that place; and that the poles have but one day and one night in the whole year.

These things premised, we shall proceed to the description and use of the terrestrial globe, and explain the geographical terms as they occur

in the problems,

The terrestrial globe described. This globe has the boundaries of land and water laid down upon it, the countries and kingdoms divided by dots, and coloured to diftinguish them, the islands properly situated, the rivers and principal towns inserted, as they have been ascertained upon the earth by measurement and observation.

The equator, ecliptic, tropics, polar circles, and meridians, are laid down upon the globe in the manner already described. The ecliptic is divided into 12 figns, and each fign into 30 degrees, which are generally fubdivided into halves, and into quarters if the globe is large. Each tropic is 231 degrees from the equator, and each polar circle 23 degrees from its respective pole. Circles are drawn parallel to the equator, at every ten degrees distance from it on each side to the poles: these circles are called parallels of latitude. On large globes there are circles drawn perpendicularly through every tenth degree of the equator, interfecting each other at the poles: but on globes of or under a foot diameter, they are only drawn through every fifteenth degree of the equator: these circles are generally called meridians, sometimes circles of longitude, and at other times bourcircles.

The globe is hung in a brass ring, called the brasen meridian; and turns upon a wire in each pole sunk half its thickness into one side of the meridian ring: by which means, that side of the ring divides the globe into two equal parts, called the eastern and western bemispheres; as the equator divides it into two equal parts, called the northern and southern bemispheres. This ring is divided

divided into 360 equal parts or degrees, on the fide wherein the axis of the globe turns. One half of these degrees are numbered, and reckoned, from the equator to the poles, where they end at 90: their use is to shew the latitudes of places. The degrees on the other half of the meridian ring are numbered from the poles to the equator, where they end at 90: their use is to shew how to elevate either the north or south pole above the horizon, according to the latitude of any given place, as it is north or south of the equator.

The brasen meridian is let into two notches made in a broad slat ring, called the wooden horizon, the upper surface of which divides the globe into two equal parts, called the upper and lower hemispheres. One notch is in the north point of the horizon, and the other in the south. On this horizon are several concentric circles, which contain the months and days of the year, the signs and degrees answering to the sun's place for each month and day, and the 32 points of the compass.—The graduated side of the brass meridian lies toward the east side of the horizon, and should be generally kept toward the person who works problems by the globes.

There is a small borary circle, so fixed to the north part of the brazen meridian, that the wire in the north pole of the globe is in the center of that circle; and on the wire is an index, which goes over all the 24 hours of the circle, as the globe is turned round its axis. Sometimes there are two horary circles, one between each pole of the globe and the brasen meridian; which is the contrivance of the late ingenious Mr. Joseph Harris, master of the Assay-office in the Tower of London; and makes it very conve-

S 2

nient

nient for putting the poles of the globe through the horizon, and for elevating the pole to small latitudes, and declinations of the sun; which cannot be done where there is only one horary circle fixed to the outer edge of the brasen meridian.

There is a thin slip of brass, called the quadrant of altitude, which is divided into 90 equal parts or degrees, answering exactly to so many degrees of the equator. It is occasionally fixed to the uppermost point of the brasen meridian by a nut and screw. The divisions end at the nut, and the quadrant is turned round upon it.

As the globe has been feen by most people, and upon the figure of which, in a plate, neither the circles nor countries can be properly expressed, we judge it would fignify very little to refer to a figure of it; and shall therefore only give some directions how to choose a globe, and then

describe its use.

Directions for choosing of globes. 1. See that the papers be well and neatly pasted on the globes, which you may know, if the lines and circles thereon meet exactly, and continue all the way even and whole; the circles not breaking into several arches, nor the papers either coming short, or lapping over one another.

2. See that the colours be transparent, and not laid too thick upon the globe to hide the names

of places.

3. See that the globe hang evenly between the brasen meridian and the wooden horizon; not inclining either to one side or to the other.

4. See that the globe be as close to the horizon and meridian as it conveniently may; otherwise, you will be too much puzzled to find against

against what part of the globe any degree of the meridian or horizon is.

5. See that the equinoctial line be even with the horizon all around, as the north or fouth pole is elevated 90 degrees above the horizon.

6. See that the equinoctial line cuts the horizon in the east and west points, in all elevations of the pole from 0 to 90 degrees.

7. See that the degree of the brasen meridian marked with 0, be exactly over the equinoctial line of the globe.

8. See that there be exactly half of the brasen meridian above the horizon; which you may know, if you bring any of the decimal divisions on the meridian to the north point of the horizon, and find their complement to 90 in the fouth point,

9. See that when the quadrant of altitude is placed as far from the equator, or the brasen meridian, as the pole is elevated above the horizon, the beginning of the degrees of the quadrant reaches just to the plane surface of the horizon.

10. See that while the index of the hourcircle (by the motion of the globe) passes from one hour to another, 15 degrees of the equator pass under the graduated edge of the brasen meridian.

11. See that the wooden horizon be made substantial and strong: it being generally observed, that in most globes, the horizon is the first part that fails, on account of its having been made too slight.

In using the globes, keep the east side of the Directihorizon toward you (unless your problem re- ons for quires the turning of it) which side you may them, know by the word East upon the horizon; for

S 3 then

then you have the graduated fide of the meridian toward you, the quadrant of altitude before you, and the globe divided exactly into two equal parts, by the graduated fide of the meridian.

In working fome problems, it will be neceffary to turn the whole globe and horizon about, that you may look on the west side thereof; which turning will be apt to jog the ball so, as to shift away that degree of the globe which was before set to the horizon or meridian: to avoid which inconvenience, you may thrust in the feather-end of a quill between the ball of the globe and the brasen meridian; which, without hurting the ball, will keep it from turning in the meridian, while you turn the west side of the horizon toward you.

### PROBLEM I.

To find the \* latitude and † longitude of any given place upon the globe.

Turn the globe on its axis, until the given place comes exactly under that graduated fide of

\* The latitude of a place is its distance from the equator, and is north or fouth, as the place is north or fouth of the equator. Those who live at the equator have no lati-

tude, because it is there that the latitude begins,

+ The longitude of a place is the number of degrees (reckoned upon the equator) that the meridian of the faid place is distant from the meridian of any other place from which we reckon, either castward or westward, for 180 degrees, or half round the globe. The British reckon the longitude from the meridian of London, and the French from the meridian of Paris. The meridian of that place, from which the longitude is reckoned, is called the surface meridian. The places upon this meridian have no longitude, because it is there that the longitude begins.

the brasen meridian, on which the degrees are numbered from the equator; and observe what degree of the meridian the place then lies under; which is its latitude, north or south, as the place is north or south of the equator.

The globe remaining in this position, the degree of the equator, which is under the brasen meridian, is the longitude of the place (from the meridian of London on the English globes) which is east or west, as the place lies on the east or west side of the first meridian of the globe.—All the Atlantic Ocean, and America, is on the west side of the meridian of London; and the greatest part of Europe, and of Africa, together with all Asia, is on the east side of the meridian of London, which is reckoned the first meridian of the globe by the British geographers and astronomers.

## PROBLEM II.

The longitude and latitude of a place being given, to find that place on the globe.

Look for the given longitude in the equator (counting it eastward or westward from the first meridian, as it is mentioned to be east or west) and bring the point of longitude in the equator to the brasen meridian, on that side which is above the south point of the horizon: then count from the equator, on the brasen meridian, to the degree of the given latitude, toward the north or south pole, according as the latitude is north or south; and under that degree of latitude on the meridian, you will have the place sequired,

#### PROBLEM III.

To find the difference of longitude, or difference of latitude, between any two given places.

Bring each of these places to the brasen meridian, and see what its latitude is: the lesser latitude substracted from the greater, if both places are on the same side of the equator, or both latitudes added together, if they are on different sides of it, is the difference of latitude required. And the number of degrees contained between these places, reckoned on the equator, when they are brought separately under the brasen meridian, is their difference of longitude; if it be less than 180: but if more, let it be substracted from 360, and the remainder is the difference of longitude required. Or,

Having brought one of the places to the brasen meridian, and set the hour index to XII, turn the globe until the other place comes to the brasen meridian, and the number of hours and parts of an hour, past over by the index, will give the longitude in time; which may be easily reduced to degrees, by allowing 15 degrees for every hour, and one degree for every four mi-

nutes.

N. B. When we speak of bringing any place to the brasen meridian, it is the graduated side of the meridian that is meant.

#### PROBLEM IV.

Any place being given, to find all those places that bave the same longitude or latitude with it.

Bring the given place to the brasen meridian. then all those places which lie under that side of the meridian, from pole to pole, have the same longitude with the given place. Turn the globe round its axis, and all those places which pass under the fame degree of the meridian that the given place does, have the fame latitude with

that place.

Since all latitudes are reckoned from the equator, and all longitudes are reckoned from the first meridian, it is evident, that the point of the equator which is cut by the first meridian, has neither latitude nor longitude.—The greatest latitude is 90 degrees, because no place is more than 90 degrees from the equator. And the greatest longitude is 180 degrees, because no place is more than 180 degrees from the first meridian.

### PROBLEM V.

To find the anteci \*, periceci +, and antipodes ‡, of any given place.

Bring the given place to the brasen meridian, and having found its latitude, keep the globe in that situation, and count the same number of degrees

<sup>\*</sup> The antaci are those people who live on the same meridian, and in equal latitudes, on different fides of the equator. Being on the same meridian, they have the same hours; that is, when it is noon to the one, it is also noon to the other; and when it is mid-night to the one, it is also midnight to the other, &c. Being on different fides of the equa-

degrees of latitude from the equator toward the contrary pole, and where the reckoning ends, you have the antaci of the given place upon the globe. Those who live at the equator have no antaci.

The globe remaining in the fame position, set the hour-index to the upper XII, on the horary circle, and turn the globe until the index comes to the lower XII; then, the place which lies under the meridian, in the same latitude with the given place, is the periaci required. Those who live at the poles have no periaci.

As the globe now stands (with the index at the lower XII) the antipodes of the given place will be under the same point of the brasen meridian where its antaci stood before. Every place upon

the globe has its antipodes.

tor, they have different or opposite seasons at the same time; the length of any day to the one is equal to the length of the night of that day to the other; and they have

equal elevations of the different poles.

+ The periaci are those people who live on the same parallel of latitude, but on opposite meridians: so that though their latitude be the same, their longitude differs 180 degrees. By being in the same latitude, they have equal elevations of the same pole (for the elevation of the pole is always equal to the latitude of the place) the same length of days or nights, and the same seasons. But being on opposite meridians, when it is noon to the one, it is midnight to the other.

† The antipodes are those who live diametrically opposite to one another upon the globe, standing with feet toward seet, on opposite meridians and parallels. Being on opposite sides of the equator, they have opposite seasons, winter to one, when it is summer to the other; being equally distant from the equator, they have their contrary poles equally elevated above the horizon; being on opposite meridians, when it is noon to the one, it must be mid-night to the other; and as the sum recedes from the one when he approaches to the other, the length of the day to one must be equal to the length of the night at the same time to the other.

#### PROBLEM VI.

To find the distance between any two places on the globe.

Lay the graduated edge of the quadrant of altitude over both the places, and count the number of degrees intercepted between them on the quadrant; then multiply these degrees by 60, and the product will give the distance in geographical miles: but to find the distance in English miles, multiply the degrees by 69½, and the product will be the number of miles required. Or, take the distance between any two places with a pair of compasses, and apply that extent to the equator; the number of degrees, intercepted between the points of the compasses, is the distance in degrees of a great circle \*; which may be reduced either to geographical miles, or to English miles, as above.

\* Any circle that divides the globe into two equal parts, Great is called a great circle, as the equator or meridian. Any circle. circle that divides the globe into two unequal parts (which every parallel of latitude does) is called a leffer circle. Now, Leffer as every circle, whether great or small, contains 360 de-circle. grees, and a degree upon the equator or meridian contains' 60 geographical miles, it is evident, that a degree of longitude upon the equator, is longer than a degree of longitude upon any parallel of latitude, and must therefore contain a greater number of miles. So that, although all the degrees of latitude are equally long upon an artificial globe (though not precifely fo upon the earth itself) yet the degrees of longitude decrease in length, as the latitude increases, but not in the same proportion. The following table shews the length of a degree of longitude, in geographical miles, and hundredth parts of a mile, for every degree of latitude, from the equator to the poles: a degree on the equator being 60 geographical miles.

### PROBLEM VII.

A place on the globe being given, and its distance from any other place, to find all the other places upon the globe which are at the same distance from the given place.

Bring the given place to the brasen meridian, and screw the quadrant of altitude to the meridian, directly over that place; then keeping the globe in that position, turn the quadrant quite round upon it, and the degree of the quadrant that touches the second place, will pass over all the other places which are equally distant with it from the given place.

This is the same as if one foot of a pair of compasses was set in the given place, and the other foot extended to the second place, whose distance is known; for if the compasses be then turned round the first place as a center, the moving foot will go over all those places which are at the same distance with the second from it.

A TABLE shewing the number of miles in a degree of longitude, in any given degree of latitude.

Deg.	Parts. Miles.	Deg.	Parts. Miles.	Deg.	Parts. Miles.
1	59.99	31	51.43	61	29.09
2	59.96	32	50.88	62	28.17
3	59.92	33	50.32	63	27.24
4	59.85	34	49.74	64	26.30
5	59-77	35	49.15	65	25.36
6	59.67	36	48.54	66	24.41
7 8	59.56	37	47.92	67	23-44
8	59.42	38	47.28	08	22.48
9	59.26	39	46.63	69	21.50
10	59.09	40	45.97	70	20.52
11	58.89	41	45.28	71	19.53
12	58.69	42	44.59	72	18.54
13	58.46	43	43.88	73	17.54
14	58.22	44	43.16	74	16.53
15	57.95	45	42.43	75	15.52
16	57.67	46	41.68	76	14.51
17	57.38	47	40.92	77	13.50
18	57.06	48	40.15	78	12.48
19	56.73	49	39.36	79	11.45
20	56.38	50	38.57	80	10.42
21	56.02	51	37.76	81	9.38
22	55.63	52	36.94	82	8.35
23	55.23	53	36.11	83	7.32
.24	54.81	54	35.27	84	6.28
25	54.38	55	34.41	85	5.24
26	53.93	56	33.55	86	4.20
27	53.46	57	32.68	87	3.15
28	52.96	58	31.79	88	2.10
29	52.47	59	30.90	89	1.05
30	51.96	60	30.00	90	0.00

## PROBLEM VIII.

The hour of the day at any place being given, to find all those places where it is noon at that time.

Bring the given place to the brasen meridian, and set the index to the given hour; this done, turn the globe until the index points to the upper XII, and then, all the places that lie under the brasen meridian have none at that time.

N. B. The upper XII always stands for noon; and when the bringing of any place to the brasen meridian is mentioned, the side of that meridian on which the degrees are reckoned from the equator is meant, unless the contrary side be mentioned.

## PROBLEM IX.

The bour of the day at any place being given, to find what time it then is at any other place.

Bring the given place to the brasen meridian, and set the index to the given hour; then turn the globe, until any place where the time is required comes to the brasen meridian, and the index will point out the time at that place.

## PROBLEM X.

To find the sun's place in the ecliptic, and his declination\*, for any given day of the year.

Look on the horizon for the given day, and right against it you have the degree of the sign in which the sun is (or his place) on that day

\* The fun's declination is his distance from the equinoctial in degrees, and is north or fouth, as the sun is between the equinoctial and the north or fouth pole.

at noon. Find the same degree of that sign in the ecliptic line upon the globe, and having brought it to the brasen meridian, observe what degree of the meridian stands over it; for that is the sun's declination, reckoned from the equator.

# PROBLEM XI.

The day of the month being given, to find all those places of the earth over which the sun will pass vertically on that day:

Find the sun's place in the ecliptic for the given day, and having brought it to the brasen meridian, observe what point of the meridian is over it; then turning the globe round its axis, all those places which pass under that point of the meridian are the places required; for as their latitude is equal, in degrees and parts of a degree, to the sun's declination, the sun must be vertical (or directly over head) to each of them at its respective noon.

# PROBLEM XII.

A place being given in the torrid zone\*, to find those two days of the year, on which the sun shall be vertical to that place.

Bring the given place to the brasen meridian, and mark the degree of latitude that is exactly over

The globe is divided into five zones; one torrid, two temperate, and two frigid. The torrid zone lies between the two tropics, and is 47 degrees in breadth, or  $23\frac{1}{2}$  on each fide of the equator: the temperate zones lie between the tropics and polar circles, or from  $23\frac{1}{2}$  degrees of latitude, to  $66\frac{1}{2}$ , on each

over it on the meridian; then turn the globe round its axis, and observe the two degrees of the ecliptic which pass exactly under that degree of latitude: lastly, find on the wooden horizon the two days of the year on which the sun is in those degrees of the ecliptic, and they are the days required: for on them, and none else, the sun's declination is equal to the latitude of the given place; and consequently, he will then be vertical to it at noon.

# PROBLEM XIII.

To find all those places of the north frigid zone, where the sun begins to shine constantly without setting, on any given day, from the 20th of March, to the 22d of September.

On these two days, the sun is in the equinoctial, and enlightens the globe exactly from pole to pole: therefore, as the earth turns round its axis, which terminates in the poles, every place upon it will go equally through the light and the dark, and so make the day and night equal to all places of the earth. But as the sun declines from the equator, toward either pole, he will shine just as many degrees round that pole, as are equal to his declination from the equator; so that no place within the distance of the pole will then go through any part of the dark, and consequently the sun will not set to it. Now, as

each fide of the equator; and are each 43 degrees in breadth: the frigid zones are the spaces included within the polar circles, which being each 23½ degrees from their respective poles, the diameter of each of these zones is 47 degrees. As the sun never goes without the tropics, he must every moment be vertical to some place or other in the torrid zone.

the fun's declination is northward, from the 20th of March to the 22d of September, he must conftantly shine round the north pole all that time; and on the day that he is in the northern tropic, he shines upon the whole north frigid zone; so that no place within the north polar circle goes through any part of the dark on that day. Therefore,

Having brought the sun's place for the given day to the brasen meridian, and sound his declination (by Prob. IX.) count as many degrees on the meridian, from the north pole, as are equal to the sun's declination from the equator, and mark that degree from the pole where the reckoning ends: then, turning the globe round its axis, observe what places in the north frigid zone pass directly under that mark; for they are the places required.

The like may be done for the fouth frigid zone, from the 22d of September to the 20th of March, during which time the fun shines constantly on the south pole.

## PROBLEM XIV.

To find the place over which the fun is vertical, at any hour of a given day.

Having found the fun's declination for the given day (by Prob. IX.) mark it with a chalk on the brasen meridian: then bring the place where you are (suppose London) to the brasen meridian, and set the index to the given hour; which done, turn the globe on its axis, until the index points to XII at noon; and the place on the globe, which is then directly under the point

of the fun's declination marked upon the meridian, has the fun that moment in the zenith, or directly over head.

## PROBLEM XV.

The day and bour at any Place being given, to find all those places where the sun is then rising, or setting, or on the meridian: consequently all those places which are enlightened at that time, and those which are in the dark.

This problem cannot be folved by any globe fitted up in the common way, with the hour circle fixed upon the brafs meridian; unless the fun be on or near fome of the tropics on the given day. But by a globe fitted up according to Mr. Joseph Harris's invention (already mentioned) where the hour-circle lies on the furface of the globe, below the meridian, it may be folved for any day in the year, according to his method; which is as follows.

Having found the place to which the fun is vertical at the given hour, if the place be in the northern hemisphere, elevate the north pole as many degrees above the horizon, as are equal to the latitude of that place; if the place be in the fouthern hemisphere, elevate the fouth pole accordingly; and bring the faid place to the brasen Then, all those places which are in the western semicircle of the horizon, have the fun rifing to them at that time; and those in the eastern semicircle have it setting: to those under the upper femicircle of the brafs meridian, it is noon; and to those under the lower semicircle, it is midnight. All those places which are above the horizon, are enlightened by the fun, and

and have the fun just as many degrees high to them, as they themselves are above the horizon: and this height may be known, by fixing the quadrant of altitude on the brasen meridian over the place to which the sun is vertical; and then, laying it over any other place, observe what number of degrees on the quadrant are intercepted between the said place and the horizon. In all those places that are 18 degrees below the western semicircle of the horizon, the morning twilight is just beginning; in all those places that are 18 degrees below the eastern semicircle of the horizon, the evening twilight is ending; and all those places that are lower than 18 degrees, have dark night.

If any place be brought to the upper femicircle of the brasen meridian, and the hour index be set to the upper XII or noon, and then the globe be turned round eastward on its axis; when the place comes to the western semicircle of the horizon, the index will shew the time of sun-rising at that place; and when the same place comes to the eastern semicircle of the horizon, the index will shew the time of sun-set.

To those places which do not go under the horizon, the sun sets not on that day: and to those which do not come above it, the sun does not rife.

## PROBLEM XVI.

The day and hour of a lunar eclipse being given; to find all those places of the earth to which it will be visible.

The moon is never eclipsed but when she is full, and so directly opposite to the sun, that the

earth's shadow falls upon her. Therefore, whatever place of the earth the sun is vertical to at that time, the moon must be vertical to the antipodes of that place: so that the sun will be then visible to one half of the earth, and the moon to the other.

Find the place to which the sun is vertical at the given hour (by Prob. XIV.) elevate the pole to the latitude of that place, and bring the place to the upper part of the brasen meridian, as in the former problem: then, as the sun will be visible to all those parts of the globe which are above the horizon, the moon will be visible to all those parts of the globe which are below it, at the time of her greatest obscuration.

But with regard to an eclipse of the sun, there is no such thing as shewing to what places it will be visible, with any degree of certainty, by a common globe; because the moon's shadow covers but a small portion of the earth's surface; and her latitude, or declination from the ecliptic, throws her shadow so variously upon the earth, that to determine the places on which it falls, recourse must be had to long calculations.

## PROBLEM XVII.

To rectify the globe for the latitude, the zenith \*, and the sun's place.

Find the latitude of the place (by Prob. I.) and if the place be in the northern hemisphere, raise the north pole above the north point of the horizon,

<sup>\*</sup> The zenith, in this fense, is the highest point of the brasen meridian above the horizon; but in the proper sense it is that point of the heaven which is directly vertical to any given place, at any given instant of time.

as many degrees (counted from the pole upon the brasen meridian) as are equal to the latitude of the place. If the place be in the fouthern hemisphere, raise the south pole above the south point of the horizon, as many degrees as are equal Then turn the globe till the to the latitude. place comes under its latitude on the brasen meridian, and fasten the quadrant of altitude so, that the chamfered edge of its nut (which is even with the graduated edge) may be joined to the This done, bring zenith, or point of latitude. the fun's place in the ecliptic for the given day, (found by Prob. X.) to the graduated fide of the brasen meridian, and set the hour-index to XII at noon, which is the uppermost XII on the hourcircle; and the globe will be rectified.

The latitude of any place is equal to the ele-Remark.

vation of the nearest pole of the heaven above the horizon of that place; and the poles of the heaven are directly over the poles of the earth, each 90 degrees from the equinoctial line. Let us be upon what place of the earth we will, if the limits of our view be not intercepted by hills, we shall see one half of the heaven, or 90 degrees every way round, from that point which is over our heads. Therefore, if we were upon the equator, the poles of the heaven would lie in our horizon, or limit of our view; if we go from the equator, toward either pole of the earth, we shall see the corresponding pole of the heaven rifing gradually above our horizon, just as many degrees as we have gone from the equator: and if we were at either of the earth's poles, the corresponding pole of the heaven would be directly over our head. Confequently, the elevation or height of the pole in

T 3 degrees

degrees above the horizon, is equal to the number of degrees that the place is from the equator.

## PROBLEM XVIII.

The latitude of any place, not exceeding \* 66½ degrees, and the day of the month, being given; to find the time of sun-rising and setting, and consequently the length of the day and night.

Having rectified the globe for the latitude, and for the fun's place on the given day (as directed in the preceding problem) bring the fun's place in the ecliptic to the eastern fide of the horizon, and the hour-index will shew the time of fun-rising; then turn the globe on its axis, until the fun's place comes to the western side of the horizon, and the index will shew the time of funfetting.

The hour of fun-fetting doubled, gives the length of the day; and the hour of fun-rifing

doubled gives the length of the night.

# PROBLEM XIX.

The latitude of any place, and the day of the month, being given; to find when the morning twilight begins, and the evening twilight ends, at that place.

This problem is often limited; for, when the fun does not go 18 degrees below the horizon, the twilight continues the whole night; and for

feveral

<sup>\*</sup> All places whose latitude is more than  $66\frac{1}{2}$  degrees, are in the frigid zones; and to those places the sun does not set in summer, for a certain number of diurnal revolutions, which occasions this limitation of latitude.

feveral nights together in fummer, between 49 and  $66\frac{1}{2}$  degrees of latitude: and the nearer to  $66\frac{1}{2}$ , the greater is the number of these nights. But when it does begin and end, the following method will shew the time for any given

day.

Rectify the globe, and bring the fun's place in the ecliptic to the eastern side of the horizon; then mark that point of the ecliptic with a chalk which is in the western side of the horizon, it being the point opposite to the sun's place: this done, lay the quadrant of altitude over the faid point, and turn the globle eastward, keeping the quadrant at the chalk-mark, until it is just 18 degrees high on the quadrant; and the index will point out the time when the morning twilight begins: for the fun's place will then be 18 degrees below the eastern side of the horizon. To find the time when the evening twilight ends, bring the fun's place to the western side of the horizon; and the point opposite to it, which was marked with the chalk, will be rifing in the east: then, bring the quadrant over that point, and keeping it thereon, turn the globe westward, until the faid point be 18 degrees above the horizon on the quadrant, and the index will shew the time when the evening twilight ends; the fun's place being then 18 degrees below the western side of the horizon.

#### PROBLEM XX.

To find on what day of the year the sun begins to shine constantly without setting, on any given place in the north frigid zone; and how long he continues to do so.

Rectify the globe to the latitude of the place, and turn it about until some point of the ecliptic, between Aries and Cancer, coincides with the north point of the horizon where the brasen meridian cuts it: then find, on the wooden horizon, what day of the year the fun is in that point of the ecliptic; for that is the day on which the fun begins to shine constantly on the given place, without fetting. This done, turn the globe until fome point of the ecliptic, between Cancer and Libra, coincides with the north point of the horizon, where the brasen meridian cuts it; and find, on the wooden horizon, on what day the fun is in that point of the ecliptic; which is the day that the fun leaves off constantly shining on the said place, and rifes and fets to it as to other places on the globe. The number of natural days, or complete revolutions of the fun about the earth, between the two days above found, is the time that the fun keeps conftantly above the horizon without fetting: for all the portion of the ecliptic, that lies between the two points which interfect the horizon in the very north, never fets below it: and there is just as much of the opposite part of the ecliptic that never rifes; therefore, the fun will keep as long constantly below the horizon in winter, as above it in fummer.

Whoever

Whoever confiders the globe, will find, that all places of the earth do equally enjoy the benefit of the fun, in respect of time, and are equally deprived of it. For, the days and nights are always equally long at the equator: and in all places that have latitude, the days at one time of the year are exactly equal to the nights at the opposite season.

#### PROBLEM XXI.

To find in what latitude the sun shines constantly without setting, for any length of time less than  $*182\frac{1}{2}$  of our days and nights.

Find a point in the ecliptic half as many degrees from the beginning of Cancer (either toward Aries or Libra) as there are natural days † in the time given; and bring that point to the north fide of the brasen meridian, on which the degrees are numbered from the pole toward the equator: then, keep the globe from turning on its axis, and slide the meridian up or down, until the aforesaid point of the ecliptic comes to the north point of the horizon, and then, the elevation of the pole will be equal to the latitude required.

+ A natural day contains the whole 24 hours: an artificial day, the time that the fun is above the horizon.

<sup>\*</sup> The reason of this limitation is, that  $182\frac{1}{2}$  of our days and nights make half a year, which is the longest time that the sun shines without setting, even at the poles of the earth.

#### PROBLEM XXII.

The latitude of a place, not exceeding  $66\frac{\pi}{2}$  degrees, and the day of the month being given: to find the sun's amplitude, or point of the compass on which he rises or sets on that day.

Rectify the globe, and bring the sun's place to the eastern side of the horizon; then observe what point of the compass on the horizon stands right against the sun's place, for that is his amplitude at rising. This done, turn the globe westward, until the sun's place comes to the western side of the horizon, and it will cut the point of his amplitude at setting. Or, you may count the rising amplitude in degrees, from the east point of the horizon, to that point where the sun's place cuts it; and the setting amplitude, from the west point of the horizon, to the fun's place at setting.

## PROBLEM XXIII.

The latitude, the sun's place, and his altitude, being given; to find the hour of the day, and the sun's azimuth, or number of degrees that he is distant from the meridian.

Rectify the globe, and bring the fun's place to the given height upon the quadrant of altitude; on the eastern side of the horizon, if the time be in the forenoon; or the western side, if

<sup>\*</sup> The fun's altitude, at any time, is his height in degrees above the horizon at that time.

it be in the afternoon: then, the index will shew the hour; and the number of degrees in the horizon intercepted between the quadrant of altitude and the south point, will be the sun's true azimuth at that time.

N. B. Always when the quadrant of altitude is mentioned in working any problem, the gra-

duated edge of it is meant.

If this be done at fea, and compared with the fun's azimuth, as shewn by the compass, if they agree, the compass has no variation in that place: but if they differ, the compass does vary; and the variation is equal to this difference.

### PROBLEM XXIV.

The latitude, bour of the day, and the sun's place, being given; to find the sun's altitude and azimuth.

Rectify the globe, and turn it until the index points to the given hour; then lay the quadrant of altitude over the fun's place in the ecliptic, and the degree of the quadrant cut by the fun's place is his altitude at that time above the horizon; and the degree of the horizon cut by the quadrant in the fun's azimuth, reckoned from the fouth.

#### PROBLEM XXV.

The latitude, the fun's altitude, and his azimuth being given; to find his place in the ecliptic, the day of the month, and bour of the day, though they had all been lost.

Rectify the globe for the latitude and zenith\*, and fet the quadrant of altitude to the given azimuth in the horizon; keeping it there, turn the globe on its axis until the ecliptic cuts the quadrant in the given altitude: that point of the ecliptic which cuts the quadrant there, will be the fun's place; and the day of the month answering thereto, will be found over the like place of the fun on the wooden horizon. Keep the quadrant of altitude in that position, and having brought the sun's place to the brasen meridian, and the hour index to XII at noon, turn back the globe, until the sun's place cuts the quadrant of altitude again, and the index will shew the hour.

Any two points of the ecliptic which are equidistant from the beginning of Cancer or of Capricorn, will have the same altitude and azimuth at the same hour, though the months be different; and therefore it requires some care in this problem, not to mistake both the month, and the day of the month; to avoid which, observe, that from the 20th of March to the 21st of June, that part of the ecliptic which is be-

<sup>\*</sup> By rectifying the globe for the zenith, is meant screwing the quadrant of altitude to the given latitude on the brass meridian.

tween the beginning of Aries and beginning of Cancer is to be used: from the 21st of June to the 22d of September, between the beginning of Cancer and beginning of Libra: from the 22d of September to the 21st of December, between the beginning of Libra and the beginning of Capricorn; and from the 21st of December to the 20th of March, between the beginning of Capricorn and beginning of Aries. And as one can never be at a loss to know in what quarter of the year he takes the sun's altitude and azimuth, the above caution with regard to the quarters of the ecliptic, will keep him right as to the month and day thereof.

## PROBLEM XXVI.

To find the length of the longest day at any given place.

If the place be on the north fide of the equator, find its latitude (by Prob. I.) and elevate the north pole to that latitude; then, bring the beginning of Cancer to the brasen meridian, and fet the hour-index to XII at noon. But if the given place be on the fouth fide of the equator, elevate the fouth pole to its latitude, and bring the beginning of Capricorn is to the brass meridian, and the hour-index to XII. This done, turn the globe westward, until the beginning of Cancer or Capricorn (as the latitude is north or fouth) comes to the horizon; and the index will then point out the time of funfetting, for it will have gone over all the afternoon hours, between mid-day and fun-fet; which

which length of time being doubled, will give the whole length of the day, from fun-rifing to fun-fetting. For, in all latitudes, the fun rifes as long before mid-day, as he fets after it.

## PROBLEM XXVII.

To find in what latitude the longest day is of any given length less than 24 hours.

If the latitude be north, bring the beginning of Cancer to the brasen meridian, and elevate the north pole to about  $66\frac{1}{3}$  degrees; but if the latitude be fouth, bring the beginning of Capricorn to the meridian, and elevate the fouth pole to about 661 degrees; because the longest day in north latitude, is when the fun is in the first point of Cancer; and in fouth latitude, when he is in the first point of Capricorn. fet the hour-index to XII at noon, and turn the globe westward, until the index points at half the number of hours given: which done, keep the globe from turning on its axis, and flide the meridian down in the notches, until the aforefaid point of the ecliptic (viz. Cancer or Capricorn) comes to the horizon; then, the elevation of the pole will be equal to the latitude required.

# PROBLEM XXVIII.

The latitude of any place, not exceeding  $66\frac{1}{2}$  degrees, being given; to find in what climate \* the place is.

Find the length of the longest day at the given place by Prob. XXVI. and whatever be the number of hours whereby it exceeds twelve, double that number, and the sum will answer to the climate, in which the place is.

#### PROBLEM XXIX.

The latitude, and the day of the month, being given; to find the hour of the day when the sun shines.

Set the wooden horizon truly level, and the brasen meridian due north and south by a mariner's compass: then, having rectified the globe, stick a small sewing needle into the sun's place in the ecliptic, perpendicular to that part of the surface of the globe: this done, turn the globe on its axis, until the needle comes to the brasen meridian, and set the hour-index to XII

<sup>\*</sup> A climate from the equator to either of the polar circles, is a tract of the earth's furface, included between two fuch parallels of latitude, that the length of the longest day in the one exceeds that in the other by half an hour; but from the polar circles to the poles, where the sun keeps long above the horizon without setting, each climate differs a whole month from the one next to it. There are twenty-four climates between the equator and each of the polar circles; and six from each polar circle to its respective pole.

at noon; then, turn the globe on its axis, until the needle points exactly toward the fun, (which it will do when it casts no shadow on the globe) and the index will so ew the hour of the day.

## PROBLEM XXX.

A pleasant way of shewing all those places of the earth which are enlightened by the sun, and also the time of the day when the sun shines.

Take the terrestrial ball out of the wooden horizon, and also out of the brasen meridian; then set it upon a pedestal in fun-shine, in such a manner, that its north pole may point directly toward the north pole of the heaven, and the meridian of the place where you are be directly toward the fouth. Then, the fun will shine upon all the like places of the globe, that he does on the real earth, rifing to some when he is fetting to others; as you may perceive by that part where the enlightened half of the globe is divided from the half in the shade, by the boundary of the light and darkness: all those places, on which the fun shines, at any time, having day; and all those, on which he does not shine, having night.

If a narrow slip of paper be put round the equator, and divided into 24 equal parts, beginning at the meridian of your place, and the hours be set to those divisions in such a manner, that one of the VI's may be upon your meridian; the sun being upon that meridian at noon, will then shine exactly to the two XII's; and at one to the two I's, &c. So that the

place,

place, where the enlightened half of the globe is parted from the shaded half, in this circle of

hours, will shew the time of the day.

The principles of dialing shall be explained farther on, by the terrestrial globe. At present we shall only add the following observations upon it; and then proceed to the use of the celeftial globe.

1. The latitude of any place is equal to the elevation of the pole above the borizon of that place, and the elevation of the equator is equal to the complement of the latitude, that is, to what the lati-

tude wants of 90 degrees.

2. Those places which lie on the equator, have no latitude, it being there that the latitude begins; and those places which lie on the first meridian have no longitude, it being there that the longitude begins. Consequently, that particular place of the earth where the first meridian intersects the equator, has neither

longitude nor latitude.

- 3. At all places of the earth, except the poles, all the points of the compass may be distinguished in the horizon: but from the north pole, every place is south; and from the south pole, every place is north. Therefore, as the sun is constantly above the horizon of each pole for half a year in its turn, he cannot be said to depart from the meridian of either pole for half a year together. Consequently, at the north pole it may be said to be noon every moment for balf a year; and let the winds blow from what part they will, they must always blow from the south; and at the south pole, from the north.
- 4. Because one half of the exliptic is above the borizon of the pole, and the sun, moon, and planets move in (or nearly in) the ecliptic; they will all rife

rise and set to the poles. But, because the stars never change their declinations from the equator, (at least not sensibly in one age) those which are once above the horizon of either pole, never set below it; and those which are once below it, never rise.

5. All places of the earth do equally enjoy the benefit of the sun, in respect of time, and are equally

deprived of it.

6. All places upon the equator have their days and nights equally long, that is, 12 hours each, at all times of the year. For although the sun declines, alternately, from the equator toward the north and toward the south, yet, as the horizon of the equator cuts all the parallels of latitude and declination in halves, the sun must always continue above the horizon for one half a diurnal revolution about the

earth, and for the other half below it.

7. When the sun's declination is greater than the latitude of any place, upon either side of the equator, the fun will come twice to the same azimuth or point of the compass in the forenoon, at that place, and twice to a like azimuth in the afternoon; that is, be will go twice back every day, while his declination continues to be greater than the latitude. suppose the globe restified to the latitude of Barbadoes, which is 13 degrees north; and the sun to be any where in the ecliptic, between the middle of Taurus and middle of Leo; if the quadrent of altitude be set to about 18 degrees \* north of the east in the horizon, the san's place be marked with a chalk upon the ecliptic, and the globe be then turned westward on its axis, the said mark will rise in the borizon a little to the north of the quadrant, and thence ascending, it will cross the quadrant toward

<sup>\*</sup> From the middle of Gemini to the middle of Cancer, the quadrant may be fet 20 degrees.

the fouth; but before it arrives at the meridian, it will cross the quadrant again, and pass over the meridian northward of Barbadoes. And if the quadrant be set about 18 degrees north of the west, the sun's place will cross it twice, as it descends from the meridian toward the horizon, in the afternoon.

8. In all places of the earth between the equator and poles, the days and nights are equally long, viz. 12 hours each, when the sun is in the equinoctial; for, in all elevations of the pole, short of 90 degrees (which is the greatest) one half of the equator or equinoctial will be above the horizon, and the other half below it.

9. The days and nights are never of an equal length at any place between the equator and polar circles, but when the fun enters the figns 

Aries and Libra. For in every other part of the ecliptic, the circle of the fun's daily motion is divided into two

unequal parts by the borizon.

10. The nearer any place is to the equator, the less is the difference between the length of the days and nights in that place; and the more remote, the contrary. The circles which the sun describes in the heaven every 24 hours, being cut more nearly equal in the former case, and more unequally in the latter.

of latitude, however long or short the day or night be at any one of these places, at any time of the year, it is then of the same length at all the rest; for in turning the globe round its axis (when rectified according to the sun's declination) all these places will keep equally long above or below the borison.

12. The sun is vertical twice a year to every place between the tropics; to those under the tropics, once

once a year, but never any where else. For, there can be no place between the tropics, but that there will be two points in the ecliptic, whose declination from the equator is equal to the latitude of that place; and but one point of the ecliptic which has a declination equal to the latitude of places on the tropic which that point of the ecliptic touches; and as the sun never goes without the tropics, he can never be vertical to any place that lies without them.

13. To all places in the torrid zone \*, the duration of the twilight is least, because the sun's daily motion is the most perpendicular to the horizon. In the frigid zones †, greatest; because the sun's daily motion is nearly parallel to the horizon; and therefore he is the longer of getting 18 degrees below it, till which time the twilight always continues. And in the temperate zones ‡ it is at a medium between the two, because the obliquity of the sun's

daily motion is fo.

14. In all places lying exactly under the polar circles, the sun, when he is in the nearest tropic, continues 24 hours above the horizon without setting; because no part of that tropic is below their horizon. And when the sun is in the farthest tropic, he is for the same length of time without rising; because no part of that tropic is above their horizon. But, at all other times of the year, he rises and sets there, as in other places; because all the circles that can be drawn parallel to the equator, between the tropics, are more or less cut by the horizon, as they are farther from, or nearer to, that tropic which is all above the horizon: and

\* Between the tropics.

<sup>†</sup> Between the polar circles and poles. ‡ Between the tropics and polar circles,

when the sun is not in either of the propies, his diurnal course must be in one or other of these circles.

15. To all places in the northern bemisphere, from the equator to the polar circle, the longest day and shortest night is when the sun is in the northern tropic; and the shortest day and longest night is when the sun is in the southern tropic; because no circle of the sun's daily motion is so much above the horizon, and so little below it, as the northern tropic; and none so little above it, and so much below it, as the southern. In the southern hemisphere, the contrary.

16. In all places between the polar circles and poles, the sun appears for some number of days (or rather diurnal revolutions) without setting; and at the opposite time of the year without rising; because some part of the ecliptic never sets in the former case, and as much of the opposite part never rises in the latter. And the nearer unto, or the more remote from the pole, these places are, the longer or shorter is the sun's continuing presence or absence.

17. If a ship sets out from any port, and sails round the earth eastward to the same port again, let her take what time she will to do it in, the people in that ship, in reckoning their time, will gain one complete day at their return, or count one day more than those who reside at the same port; because, by going contrary to the sun's diurnal motion, and being forwarder every evening than they were in the morning, their horizon will get so much the sooner above the setting sun, than if they had kept for a whole day at any particular place. And thus, by cutting off a part proportionable to their own motion, from the length of every day, they will gain a complete day of that sort at their return; without gaining one moment of absolute time more U3

than is elapsed during their course, to the people at the port. If they sail westward, they will reckon one day less than the people do who reside at the faid port, because, by gradually following the apparent diurnal motion of the sun, they will keep bim each particular day so much longer above their borizon, as answers to that day's course; and by that means, they cut off a whole day in reckoning, at their return, without losing one moment of absolute time.

Hence, if two ships should set out at the same time from any port, and sail round the globe, one eastward and the other westward, so as to meet at the same port on any day whatever; they will differ two days in reckoning their time, at their return. If they sail twice round the earth, they will differ

four days; if thrice, then fix, &c.

### LECT. IX.

The use of the celestial globe, and armillary Sphere.

The celef- I TAVING done for the present with the tial glabe. I terrestrial globe, we shall proceed to the use of the celeftial; first premising, that as the equator, ecliptic, tropics, polar circles, horizon, and brasen meridian, are exactly alike on both globes, all the former problems concerning the fun are folved the fame way by both globes. The method also of rectifying the celeftial globe is the fame as rectifying the terrestrial, viz. Elevate the pole according to the latitude of your place, then screw the quadrant of altitude to the zenith, on the brass meridian; bring the fun's place in the ecliptic to the graduated edge of the brafs meridian, on the fide

To rectify it.

fide which is above the fouth point of the wooden horizon, and fet the hour-index to the upper-most XII, which stands for noon.

N. B. The fun's place for any day of the year flands directly over that day on the horizon of the celestial globe, as it does on that of the terrestrial.

The latitude and longitude of the stars, and of Latitude all other celestial phenomena, are reckoned in a and longivery different manner from the latitude and tude of longitude of places on the earth: for all terref- the flars. trial latitudes are reckoned from the equator; and longitudes from the meridian of some remarkable place, as of London by the British, and of Paris by the French; though most of the French maps begin their longitude at the meridian of the island Ferro. But the astronomers of all nations agree in reckoning the latitudes of the moon, stars, planets, and comets, from the ecliptic; and their longitudes from the equinoEtial colure \*, in that semicircle of it which cuts the ecliptic at the beginning of Aries v; and thence eastward, quite round, to the same femicircle again. Confequently those stars which lie between the equinoctial and the northern half of the ecliptic, have north declination and fouth latitude; those which lie between the equinoctial and the fouthern half of the ecliptic, have fouth declination and north latitude; and

<sup>\*</sup> The great circle that passes through the equinoctial points at the beginning of  $\varphi$  and  $\triangle$ , and through the poles of the world (which are two opposite points, each 90 degrees from the equinoctial) is called the equinoctial colure: Colures, and the great circle that passes through the beginning of  $\boxtimes$  and  $\bowtie$ , and also through the poles of the ecliptic, and poles of the world, is called the folsitial colure.

all those which lie between the tropics and poles, have their declinations and latitudes of the same denomination.

There are fix great circles on the celestial globe, which cut the ecliptic perpendicularly, and meet in two opposite points in the polar circles; which points are each ninety degrees from the ecliptic, and are called its poles. These polar points divide those circles into 12 femicircles; which cut the ecliptic at the beginnings of the 12 figns. They refemble fo many meridians on the terrestrial globe; and as all places which lie under any particular meridian femicircle on that globe, have the fame longitude, fo all those points of the heaven, through which any one of the above femicircles are drawn, have the fame longitude .- And as the greatest latitudes on the earth are at the north and fouth poles of the earth, so the greatest latitudes in the heaven, are at the north and fouth poles of the ecliptic.

Constella-

In order to distinguish the stars, with regard to their situations and positions in the heaven, the ancients divided the whole visible sirmament of stars into particular systems, which they called constellations; and digested them into the forms of such animals as are delineated upon the celestial globe. And those stars which lie between the sigures of those imaginary animals, and could not be brought within the compass of any of them, were called unformed stars.

Because the moon and all the planets were observed to move in circles or orbits which cross the ecliptic (or line of the sun's path) at small angles, and to be on the north side of the ecliptic for one half of their course round the heaven of stars, and on the south side of it for the

other

other half, but never to go quite 8 degrees from it on either side, the ancients distinguished that space by two lesser circles, parallel to the ecliptic (one on each side) at 8 degrees distance from it. And the space included between the circles, they called the zodiac, because most of the 12 Zodiac. constellations placed therein resemble some living creature.—These constellations are, 1. Aries v, the ram; 2. Taurus, 8, the bull; 3. Gemini II, the twins; 4. Cancer I, the crab; 5. Leo A, the lion; 6. Virgo I, the virgin; 7. Libra I, the balance; 8. Scorpio III, the scorpion; 9. Sagittarius I, the archer; 10. Capricornus II, the goat; 11. Aquarius III, the water-bearer; and 12. Pisces X, the sishes.

It is to be observed, that in the infancy of Remark, astronomy, these twelve constellations stood at or near the places of the ecliptic, where the above characteristics are marked upon the globe: but now, each constellation has got a whole sign forwarder, on account of the recession of the equinoctial points from their former places. So that the constellation of Aries, is now in the former place of Taurus; that of Taurus, in the

former place of Gemini; and fo on.

The stars appear of different magnitudes to the eye; probably because they are at different distances from us. Those which appear brightest and largest, are called stars of the sirst magnitude; the next to them in size and lustre, are called stars of the second magnitude; and so on to the sixth, which are the smallest that can be discerned by the bare eye.

Some of the most remarkable stars have names given them, as Castor and Pollux in the heads of the Twins, Sirius in the mouth of the Great Dog, Procyon in the side of the Little Dog, Rigel

in the left foot of Orion, Arcturus near the right

thigh of Bootes, &c.

These things being premised, which I think are all that the young Tyro need be acquainted with, before he begins to work any problem by this globe, we shall now proceed to the most useful of those problems; omitting several which are of little or no consequence.

#### PROBLEM I.

To find the right ascension \* and declination † of the fun, or any fixed star.

Bring the fun's place in the ecliptic to the brasen meridian, then that degree in the equinoctial which is cut by the meridian, is the sun's right ascension; and that degree of the meridian which is over the sun's place, is his declination. Bring any fixed star to the meridian, and its right ascension will be cut by the meridian in the equinoctial; and the degree of the meridian that stands over it, is its declination.

So that right afcension and declination, on the celestial globe, are found in the same manner as longitude and latitude on the terrestrial.

\* The degree of the equinoctial, reckoned from the beginning of Aries, that comes to the meridian with the sun or star, is its right ascension.

† The distance of the sun or star in degrees from the equinoctial, toward either of the poles, north or south, is its declination, which is north or south accordingly.

## PROBLEM II.

To find the latitude and longitude of any star.

If the given star be on the north side of the ecliptic, place the 90th degree of the quadrant of altitude on the north pole of the ecliptic, where the twelve semicircles meet; which divide the ecliptic into the 12 figns: but if the flar be on the fouth fide of the ecliptic, place the 90th degree of the quadrant on the fouth pole of the ecliptic: keeping the 90th degree of the quadrant on the proper pole, turn the quadrant about, until its graduated edge cuts the flar; then, the number of degrees in the quadrant, between the ecliptic and the star, is its latitude; and the degree of the ecliptic cuts by the quadrant is the star's longitude, reckoned according to the fign in which the quadrant then is.

# PROBLEM III.

To represent the face of the starry sirmament, as seen from any given place of the earth, at any bour of the night.

Rectify the celestial globe for the given latitude, the zenith, and sun's place, in every respect, as taught by the 17th problem, for the terrestrial; and turn it about, until the index points to the given hour: then, the upper hemisphere of the globe will represent the visible half of the heaven for that time: all the stars

upon the globe being then in fuch fituations, as exactly correspond to those in the heaven. And if the globe be placed duly north and fouth, by means of a finall fea-compass, every star on the globe will point toward the like ftar in the heaven: by which means, the constellations and remarkable stars may be easily known. those stars which are in the eastern side of the horizon, are then rifing in the eaftern fide of the heaven: all in the western, are setting in the western side; and all those under the upper part of the brasen meridian, between the south point of the horizon and the north pole, are at their greatest altitude, if the latitude of the place be north: but if the latitude be fouth, those stars which lie under the upper part of the meridian, between the north point of the horizon and the fouth pole, are at their greatest altitude.

# PROBLEM IV.

The latitude of the place, and day of the month being given; to find the time when any known star will rise, or be on the meridian, or set.

Having rectified the globe, turn it about until the given star comes to the eastern side of the horizon, and the index will shew the time of the star's rising; then turn the globe westward, and when the star comes to the brasen meridian, the index will shew the time of the star's coming to the meridian of your place; lastly, turn on, until the star comes to the western side of the horizon, and the index will shew the time of the star's setting.

N. B.

N. B. In northern latitudes, those stars which are less distant from the north pole, than the quantity of its elevation above the north point of the horizon, never set; and those which are less distant from the south pole, than the number of degrees by which it is depressed below the horizon, never rise; and vice versa in southern latitudes.

#### PROBLEM V.

To find at what time of the year a given star will be upon the meridian, at a given bour of the night.

Bring the given star to the upper semicircle of the brass meridian, and set the index to the given hour; then turn the globe, until the index points to XII at noon, and the upper semicircle of the meridian will then cut the sun's place, answering to the day of the year sought; which day may be easily sound against the like place of the sun among the signs on the wooden horizon.

# PROBLEM VI.

The latitude, day of the month, and azimuth \* of any known star being given; to find the hour of the night.

Having rectified the globe for the latitude, zenith, and fun's place; lay the quadrant of

<sup>\*</sup> The number of degrees, that the fun, moon, or any flar, is from the meridian, either to the east or west, is called its azimuth.

altitude to the given degree of azimuth in the horizon: then turn the globe on its axis, until the star comes to the graduated edge of the quadrant; and when it does, the index will point out the hour of the night.

#### PROBLEM VII.

The latitude of the place, the day of the month, and altitude \* of any known star, being given; to find the bour of the night.

Rectify the globe as in the former problem, guess at the hour of the night, and turn the globe until the index points at the supposed hour; then lay the graduated edge of the quadrant of altitude over the known star, and if the degree of the star's height in the quadrant upon the globe, answers exactly to the degree of the star's observed altitude in the heaven, you have guessed exactly: but if the star on the globe is higher or lower than it was observed to be in the heaven, turn the globe backward or forward, keeping the edge of the quadrant upon the star, until its center comes to the observed altitude in the quadrant; and then, the index will shew the true time of the night.

<sup>\*</sup> The number of degrees that the star is above the horizon, as observed by means of a common quadrant, is called its altitude.

## PROBLEM VIII.

An easy method for finding the hour of the night by any two known stars, without knowing either their altitude or azimuth; and then, of finding both their altitude and azimuth, and thereby the true meridian.

Tie one end of a thread to a common musket bullet; and having rectified the globe as above, hold the other end of the thread in your hand, and carry it flowly round between your eye and the starry heaven, until you find it cuts any two known stars at once. Then, guesfing at the hour of the night, turn the globe until the index points to the time in the hour-circle; which done, lay the graduated edge of the quadrant over any one of these two stars on the globe, which the thread cut in the heaven. If the faid edge of the quadrant cuts the other star also, you have gueffed the time exactly; but if it does not, turn the globe flowly backward or forward, until the quadrant (kept upon either star) cuts them both through their centers: and then. the index will point out the exact time of the night; the degree of the horizon, cut by the quadrant, will be the true azimuth of both thefe ftars from the fouth; and the ftars themselves will cut their true altitudes in the quadrant. which moment, if a common azimuth compass be fo fet upon a floor or level payment, that these stars in the heaven may have the same bearing upon it (allowing for the variation of the needle) as the quadrant of altitude has in the wooden horizon of the globe, a thread extended over the north and fouth points of that compass.

will be directly in the plane of the meridian: and if a line be drawn upon the floor or pavement, along the course of the thread, and an upright wire be placed in the southermost end of the line, the shadow of the wire will fall upon that line, when the sun is on the meridian, and shines upon the pavement.

#### PROBLEM IX.

To find the place of the moon, or of any planet; and thereby to shew the time of its rising, southing, and setting.

Seek in the Nautical Almanac or White's Ephemeris, the geocentric place \* of the moon or planet in the ecliptic for the given day of the month, and, according as its longitude and latitude is found, mark the fame with a chalk upon the globe. Then, having rectified the globe, turn it round its axis westward; and as the said mark comes to the eastern side of the horizon, to the brasen meridian, and to the western side of the horizon, the index will shew at what time the planet rises, comes to the meridian, and sets, in the same manner as it would do for a fixed star.

# PROBLEM X.

To explain the phenomena of the harvest moon.

In order to do this, we must premise the following things: 1. That as the sun goes only

<sup>\*</sup> The place of the moon or planet, as feen from the earth, is called its geocentric place,

once a year round the ecliptic, he can be but once a year in any particular point of it: and that his motion is almost a degree every 24 hours, at a mean rate. 2. That as the moon goes round the ecliptic once in 27 days and 8 hours, the advances 13' degrees in it, every day at a mean rate. 3. That as the fun goes through part of the ecliptic in the time the moon goes round it, the moon cannot at any time be either in conjunction with the fun, or opposite to him, in that part of the ecliptic where she was fo the last time before; but must travel as much forwarder, as the fun has advanced in the faid time; which being 291 days, makes almost a whole fign. Therefore, 4. The moon can be but once a year opposite to the sun, in any particular part of the ecliptic. 5. That the moon is never full but when she is opposite to the fun, because at no other time can we see all that half of her, which the fun enlightens. 6. That when any point of the ecliptic rifes, the opposite Therefore, when the moon is oppofite to the fun, she must rise at \* sun set. 7. That the different figns of the ecliptic rife at very different angles or degrees of obliquity with the horizon, especially in considerable latitudes; and that the smaller this angle is, the greater is the portion of the ecliptic that rifes in any fmall part of time; and vice versa. 8. That, in northern latitudes, no part of the ecliptic rifes at fo small an angle with the horizon, as Pisces and Aries do; therefore, a greater portion of the ecliptic rifes in

<sup>\*</sup> This is not always strictly true, because the moon does not keep in the ecliptic, but crosses it twice every month. However, the difference need not be regarded in a general explanation of the cause of the harvest moon.

one hour, about these signs, than about any of the rest. 9. That the moon can never be full in Pisces and Aries but in our autumnal months, for at no other time of the year is the fun in the

opposite signs Virgo and Libra.

These things premised, take 132 degrees of the ecliptic in your compasses, and beginning at Pisces, carry that extent all round the ecliptic, marking the places with a chalk, where the points of the compasses successively fall. So you will have the moon's daily motion marked out for one complete revolution in the ecliptic; accord-

ing to § 2 of the last paragraph.

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Rectify the globe for any confiderable northern latitude (as suppose that of London) and then, turning the globe round its axis, observe how much of the hour circle the index has gone over, at the rifing of each particular mark on the ecliptic; and you will find that feven of the marks (which take in as much of the ecliptic as the moon goes through in a week) will all rife fuccessively about Pisces and Aries in the time that the index goes over two hours. Therefore, while the moon is in Pisces and Aries, she will not differ in general above two hours in her rifing for a whole week. But if you take notice of the marks on the opposite signs, Virgo and Libra, you will find that feven of them take nine hours to rife; which shews, that when the moon is in these two signs, she differs nine hours in her rifing within the compass of a week. much later as every mark is of rifing than the one that rose next before it, so much later will the moon be of rifing on any day than she was on the day before, in the corresponding part of the The marks about Cancer and Capricorn heaven. rife

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rife at a mean difference of time between those about Aries and Libra.

Now, although the moon is in Pisces and Aries every month, and therefore must rise in those figns within the space of two hours later for a whole week, or only about 17 minutes later every day than she did on the former; yet she is never full in these signs, but in our autumnal months, August and September, when the fun is in Virgo and Libra. Therefore, no full moon in the year will continue to rife fo near the time of fun fet for a week or fo, as these two full moons

do, which fall in the time of harvest.

In the winter months, the moon is in Pifces and Aries about her first quarter; and as these figns rife about noon in winter, the moon's rifing in them passes unobserved. In the spring months, the moon changes in these signs, and consequently rifes at the same time with the sun; so that it is impossible to see her at that time. the fummer months she is in these signs about her third quarter, and rifes not until mid-night, when her rifing is but very little taken notice of, especially as she is on the decrease. the harvest months she is at the full, when in these signs, and being opposite to the sun, she rifes when the fun fets (or foon after) and shines all the night.

In fouthern latitudes, Virgo and Libra rife at as small angles with the horizon, as Pisces and Aries do in the northern; and as our fpring is at the time of their harvest, it is plain their harvest full moons must be in Virgo and Libra; and will therefore rise with as little difference of time, as

ours do in Pisces and Aries.

For a fuller account of this matter, I must refer the reader to my Astronomy, in which it is described at large.

## PROBLEM XI.

To explain the equation of time, or difference of time between well regulated clocks and true fun-dials.

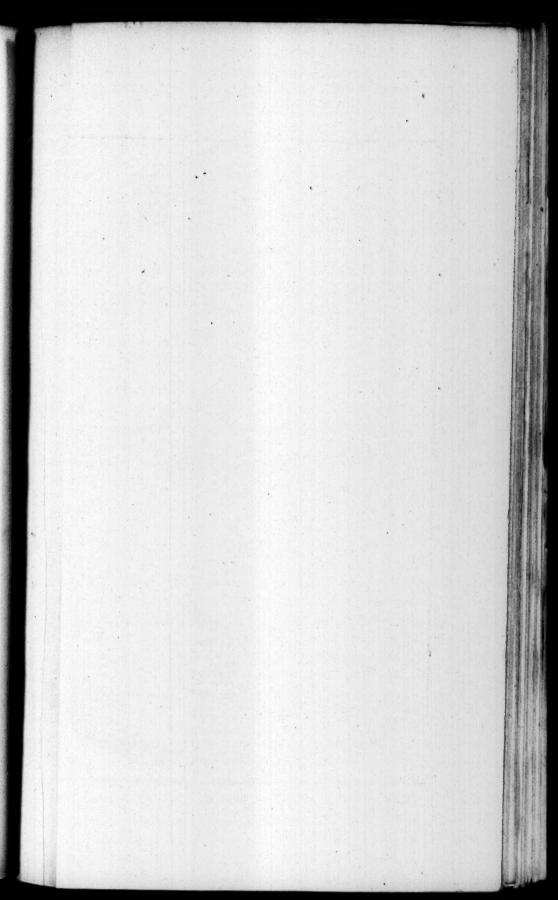
The earth's motion on its axis being perfectly equable, and thereby caufing an apparent equable motion of the starry heaven round the same axis, produced to the poles of the heaven; it is plain that equal portions of the celestial equator pass over the meridian in equal parts of time, beeause the axis of the world is perpendicular to the plane of the equator. And therefore, if the fun kept his annual course in the celestial equator, he would always revolve from the meridian to the meridian again in 24 hours exactly, as shewn by a well-regulated clock.

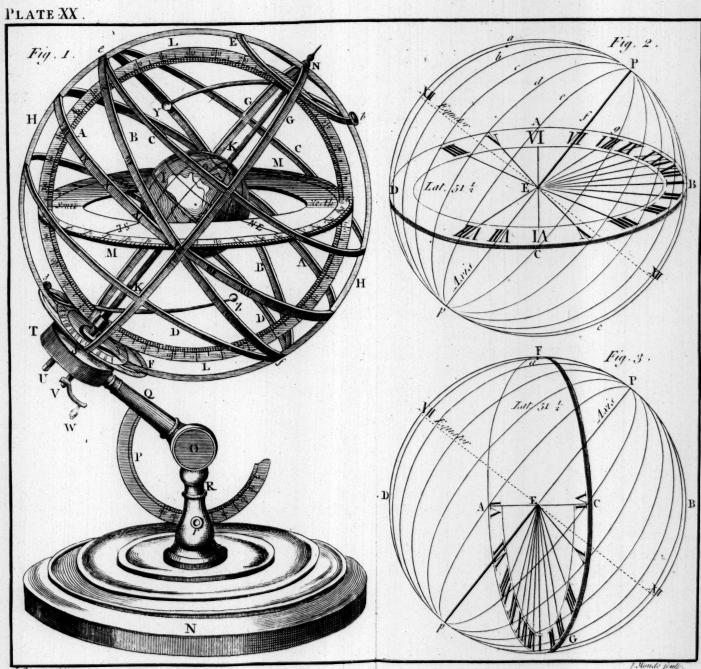
But as the fun moves in the ecliptic, which is oblique both to the plane of the equator and axis of the world, he cannot always revolve from the meridian to the meridian again in 24 equal hours; but sometimes a little sooner, and at other times a little later, because equal portions of the ecliptic pass over the meridian in unequal parts of time on account of its obliquity. And this dif-

ference is the fame in all latitudes.

To shew this by a globe, make chalk-marks all round the equator and ecliptic, at equal distances from one another (suppose 10 degrees) beginning at Aries or at Libra, where these two Then turn the circles interfect each other.

globe





globe round its axis, and you will see that all the marks in the first quadrant of the ecliptic, or from the beginning of Aries to the beginning of Cancer, come sooner to the brasen meridian than their corresponding marks do on the equator; those on the second quadrant, or from the beginning of Cancer to the beginning of Libra, come later: those in the third quadrant, from Libra to Capricorn, sooner; and those in the sourth, from Capricorn to Aries, later. But those at the beginning of each quadrant come to the meridian at the same time with their corresponding marks on the equator.

Therefore, while the sun is in the first and third quadrants of the ecliptic, he comes sooner to the meridian every day than he would do if he kept in the equator; and consequently he is safter than a well regulated clock, which always keeps equable or equatorial time: and while he is in the second and sourth quadrants, he comes later to the meridian every day than he would do if he kept in the equator; and is therefore slower than the clock. But at the beginning of each quadrant, the sun and clock are equal.

And thus, if the fun moved equably in the ecliptic, he would be equal with the clock on four days, of the year, which would have equal intervals of time between them. But as he moves faster at some times than at others (being eight days longer in the northern half of the ecliptic than in the southern) this will cause a second inequality; which combined with the former, arising from the obliquity of the ecliptic to the equator, makes up that difference, which is shewn by the common equation tables to be between good clocks and true sun-dials.

X 3

The

The description and use of the armillary sphere.

Plate XX. Fig. 1.

Whoever has feen a common armillary sphere, and understands how to use it, must be sensible that the machine here referred to, is of a very different, and much more advantageous con-And those who have feen the curious glass sphere invented by Dr. Long, or the figure of it in his Astronomy, must know that the furniture of the terrestrial globe in this machine, the form of the pedestal, and the manner of turning either the earthly globe, or the circles which furround it, are all copied from the Doctor's glass sphere; and that the only difference is, a parcel of rings instead of a glass celeftial globe; and all the additions are a moon within the fphere, and a femicircle upon the pedestal.

The armillary Sphere.

The exterior parts of this machine are a compages of brass rings, which represent the principal circles of the heaven, viz. 1. The equinoctial AA, which is divided into 360 degrees (beginning at its intersection with the ecliptic in Aries) for shewing the sun's right ascension in degrees; and also into 24 hours, for shewing his right ascension in time. 2. The ecliptic BB, which is divided into 12 figns, and each fign into 30 degrees, and also into the months and days of the year; in fuch a manner, that the degree or point of the ecliptic in which the fun is, on any given day, stands over that day in the circle of months. 3. The tropic of Cancer CC, touching the ecliptic at the beginning of Cancer in e, and the tropic of Capricorn DD, touching the ecliptic at the beginning of Capricorn in f; each 23; degrees from

from the equinoctial circle. 4. The arctic circle E, and the antarctic circle F, each 23' degrees from its respective pole at N and S. 5. The equinoctial colour GG, passing through the north and fouth poles of the heaven at N and S, and through the equinoctial points Aries, and Libra in the Ecliptic. 6. The folfitial colure HH, paffing through the poles of the heaven, and through the folftitial points Cancer and Capricorn, in the ecliptic. Each quarter of the former of these colures is divided into 90 degrees, from the equinoctial to the poles of the world, for shewing the declination of the fun, moon, and stars; and each quarter of the latter, from the ecliptic at e and f, to its poles b and d, for shewing the latitude of the stars.

In the north pole of the ecliptic is a nut b, to which is fixed one end of a quadrantal wire, and to the other end a small sun T, which is carried round the ecliptic B B, by turning the nut: and in the south-pole of the ecliptic is a pin at d, on which is another quadrantal wire, with a small moon Z upon it, which may be moved round by hand: but there is a particular contrivance for causing the moon to move in an orbit which crosses the ecliptic at an angle of 5 degrees, in two opposite points called the moon's nodes: and also for shifting these points backward in the ecliptic, as the moon's nodes shift in the heaven.

Within these circular rings is a small terrestrial globe I, fixt on an axis KK, which extends from the north and south poles of the globe at n and x, to those of the celestial sphere at N and S. On this axis is fixt the stat celestial meridian L L, which may be set directly over the meridian of any place on the globe, and then turned round with the globe, so as to keep over the same X 4

meridian upon it. This flat meridian is graduated the fame way as the brafs meridian of a common globe, and its use is much the fame. To this globe is fitted the moveable horizon MM, fo as to turn upon two strong wires proceeding from its east and west points to the globe, and entering the globe at opposite points of its equator, which is a moveable brass ring let into the globe in a groove all around its equator. The globe may be turned by hand within this ring, fo as to place any given meridian upon it, directly under the celestial meridian LL. The horizon is divided into 360 degrees all around its outermost edge, within which are the points of the compass, for shewing the amplitude of the fun and moon, both in degrees and points. The celestial meridian LL passes through two notches in the north and fouth points of the horizon, as in a common globe: but here, if the globe be turned round, the horizon and meridian turn with it. At the fouth pole of the fphere is a circle of 24 hours, fixt to the rings, and on the axis is an index which goes round that circle, if the globe be turned round its axis.

The whole fabric is supported on a pedestal N, and may be elevated or depressed upon the joint O, to any number of degrees from 0 to 90, by means of the arc P, which is fixed in the strong brass arm  $\mathcal{Q}$ , and slides in the upright piece R, in which is a screw at r, to fix it at any proper elevation.

In the box T are two wheels (as in Dr. Long's sphere) and two pinions, whose axes come out at V and U; either of which may be turned by the small winch W. When the winch is put upon the axis V, and turned backward, the ter-

restrial

restrial globe, with its horizon and celestial meridian, keep at rest; and the whole sphere of circles turns round from east, by fouth, to west, carrying the fun  $\Upsilon$ , and moon Z, round the fame way, and causing them to rise above, and set below the horizon. But when the winch is put upon the axis U, and turned forward, the fphere with the fun and moon keep at rest; and the earth, with its horizon and meridian, turn round from west, by fouth, to east: and bring the same points of the horizon to the fun and moon, to which these bodies came when the earth kept at rest, and they were carried round it; shewing that they rife and fet in the fame points of the horizon, and at the fame time in the hour-circle, whether the motion be in the earth or in the If the earthly globe be turned, the heaven. hour-index goes round its hour-circle; but if the sphere be turned, the hour-circle goes round below the index.

And fo, by this conftruction, the machine is equally fitted to shew either the real motion of the earth, or the apparent motion of the heaven.

To rectify the sphere for use, first slacken the screw r in the upright stem R, and taking hold of the arm  $\mathcal{Q}$ , move it up or down until the given degree of latitude for any place be at the side of the stem R; and then the axis of the sphere will be properly elevated, so as to stand parallel to the axis of the world, if the machine be set north and south by a small compass: this done, count the latitude from the north pole, upon the celestial meridian LL, down toward the north notch of the horizon, and set the horizon to that latitude; then, turn the nut b until the sun  $\mathcal{X}$  comes to the given day of the year in

the ecliptic, and the sun will be at its proper place for that day: find the place of the moon's ascending node, and also the place of the moon, by an Ephemeris, and set them right accordingly: lastly, turn the winch W, until either the sun comes to the meridian LL, or until the meridian comes to the fun (according as you want the sphere or earth to move) and set the hourindex to the XII, marked noon, and the whole machine will be rectified.—Then turn the winch, and observe when the sun or moon rise or set in the horizon, and the hour-index will shew the times thereof for the given day.

As those who understand the use of the globes will be at no loss to work many other problems by this sphere, it is needless to enlarge any far-

ther upon it.

## LECT. X.

The principles and art of dialing.

Preliminaries. A Dial is a plane, upon which lines are deferibed in such a manner, that the shadow of a wire, or of the upper edge of a plate stile, erected perpendicularly on the plane of the dial, may shew the true time of the day.

The edge of the plate by which the time of the day is found, is called the stile of the dial, which must be parallel to the earth's axis; and the line on which the said plate is erected, is

called the substile.

The angle included between the fubstile and stile, is called the elevation, or height of the stile.

Those dials whose planes are parallel to the plane of the horizon, are called horizontal dials;

and those dials whose planes are perpendicular to the plane of the horizon, are called vertical, or erect sun-dials.

Those erect dials, whose planes directly front the north or south, are called direct north or south dials; and all other erect dials are called decliners, because their planes are turned away from the north or south.

Those dials, whose planes are neither parallel nor perpendicular to the plane of their horizon, are called inclining, or reclining dials, according as their planes make acute or obtuse angles with the horizon; and if their planes are also turned aside from facing the south or north, they are called declining-inclining, or declining-reclining dials.

The intersection of the plane of the dial, with that of the meridian, passing through the stile, is called the meridian of the dial, or the hourline of XII.

Those meridians, whose planes pass through the stile, and make angles of 15, 30, 45, 60, 75, and 90 degrees with the meridian of the place (which marks the hour-line of XII) are called hour-circles; and their intersections with the plane of the dial, are called hour-lines.

In all declining dials, the fubstile makes an angle with the hour-line of XII; and this angle is called the distance of the substile from the meridian.

The declining plane's difference of longitude, is the angle formed at the interfection of the stile and plane of the dial, by two meridians; one of which passes through the hour-line of XII, and the other through the substile.

This much being premised concerning dials in general, we shall now proceed to explain the different methods of their construction.

Plate XX.

The univerfal principle on which dialing depends.

If the whole earth a P c p were transparent, and hollow, like a sphere of glass, and had its equator divided into 24 equal parts by fo many meridian femicircles, a, b, c, d, e, f, g, &c. one of which is the geographical meridian of any given place as London, which is supposed to be at the point a; and if the hours of XII were marked at the equator, both upon that meridian and the opposite one, and all the rest of the hours in order on the rest of the meridians, those meridians would be the hour-circles of London: then, if the sphere had an opaque axis, as P E p, terminating in the poles P and p, the shadow of the axis would fall upon every particular meridian and hour, when the fun came to the plane of the opposite meridian, and would consequently shew the time at London, and at all other places on the meridian of London.

Harizon-

If this sphere was cut through the middle by a solid plane ABCD, in the rational horizon of London, one half of the axis EP would be above the plane, and the other half below it; and if straight lines were drawn from the center of the plane, to those points where its circumference is cut by the hour-circles of the sphere, those lines would be the hour-lines of a borizontal dial for London: for the shadow of the axis would fall upon each particular hour-line of the dial, when it sell upon the like hour-circle of the sphere.

Fig. 3.

If the plane which cuts the sphere be upright, as AFCG, touching the given place (London) at F, and directly facing the meridian of London,

don, it will then become the plane of an erect direct fouth dial; and if right lines be drawn Vertical from its center E, to those points of its circum-dial. ference where the hour-circles of the fphere cut it, these will be the hour-lines of a vertical or direct fouth dial for London, to which the hours are to be fet as in the figure (contrary to those on a horizontal dial) and the lower half E p of the axis will cast a shadow on the hour of the day in this dial, at the same time that it would fall upon the like hour-circle of the fphere, if the

dial plane was not in the way.

If the plane (still facing the meridian) be Inclining made to incline, or recline, by any given number and reof degrees, the hour-circles of the sphere will clining still cut the edge of the plane in those points to which the hour-lines must be drawn straight from the center; and the axis of the sphere will cast a shadow on these lines at the respective hours. The like will still hold, if the plane be Declining made to decline by any given number of degrees dials. from the meridian, toward the east or west: provided the declination be less than 90 degrees. or the reclination be less than the co-latitude of the place: and the axis of the sphere will be a gnomon, or stile, for the dial. But it cannot be a gnomon, when the declination is quite 90 degrees, nor when the reclination is equal to the co-latitude; because in these two cases, the axis has no elevation above the plane of the dial.

And thus it appears, that the plane of every dial represents the plane of some great circle upon the earth; and the gnomon the earth's axis, whether it be a fmall wire, as in the above figures, or the edge of a thin plate, as in the common horizontal dials.

The whole earth, as to its bulk, is but a point, if compared to its distance from the sun; and therefore, if a small sphere of glass be placed upon any part of the earth's surface, so that its axis be parallel to the axis of the earth, and the sphere have such lines upon it, and such planes within it, as above described: it will shew the hours of the day as truly as if it were placed at the earth's center, and the shell of the earth were as transparent as glass.

Fig. 2, 3.

But because it is impossible to have a hollow sphere of glass perfectly true, blown round a solid plane; or if it was, we could not get at the plane within the glass to set it in any given position; we make use of a wire sphere to explain the principles of dialing, by joining 24 semicircles together at the poles, and putting a thin slat plate of brass within it.

Dialing by the common terrestrial globe.

A common globe, of 12 inches diameter, has generally 24 meridian femicircles drawn upon If fuch a globe be elevated to the latitude of any given place, and turned about until any one of these meridians cuts the horizon in the north point, where the hour of XII is supposed to be marked, the rest of the meridians will cut the horizon at the respective distances of all the other hours from XII. Then, if these points of distance be marked on the horizon, and the globe be taken out of the horizon, and a flat board or plate be put into its place, even with the furface of the horizon; and if straight lines be drawn from the center of the board, to those points of distance on the horizon which were cut by the 24 meridian femicircles, these lines will be the hour-lines of a horizontal dial for that latitude, the edge of whose gnomon must be in the very fame fituation that the axis of the globe

globe was, before it was taken out of the horizon: that is, the gnomon must make an angle with the plane of the dial, equal to the latitude

of the place for which the dial is made.

If the pole of the globe be elevated to the colatitude \* of the given place, and any meridian be brought to the north point of the horizon, the rest of the meridians will cut the horizon in the respective distances of all the hours from XII, for a direct fouth dial, whose gnomon must make an angle with the plane of the dial, equal to the co-latitude of the place; and the hours must be fet the contrary way on this dial, to what they are on the horizontal.

But if your globe have more than 24 meridian femicircles upon it, you must take the following method for making borizontal and fouth dials

by it.

Elevate the pole to the latitude of your place, To conand turn the globe until any particular meridian fruct a (suppose the first) comes to the north point of horizontal the horizon, and the opposite meridian will cut the horizon in the fouth. Then, fet the hourindex to the uppermost XII on its circle; which done, turn the globe westward until 15 degrees of the equator pass under the brasen meridian, and then the hour-index will be at I (for the fun moves 15 degrees every hour) and the first meridian will cut the horizon in the number of degrees from the north point, that I is distant from Turn on, until other 15 degrees of the equator pass under the brasen meridian, and the hour-index will then be at II, and the first me-

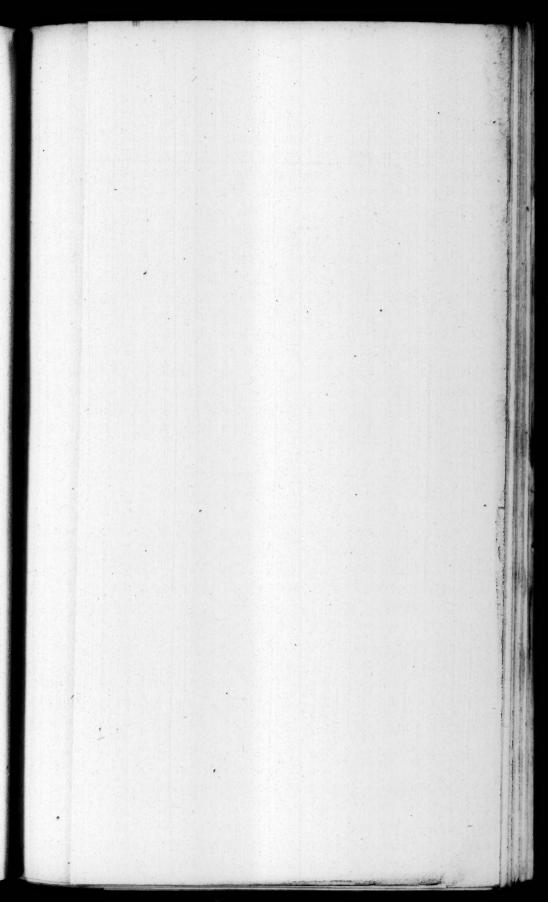
If the latitude be subtracted from 90 degrees, the remainder is called the co-latitude, or complement of the latitude.

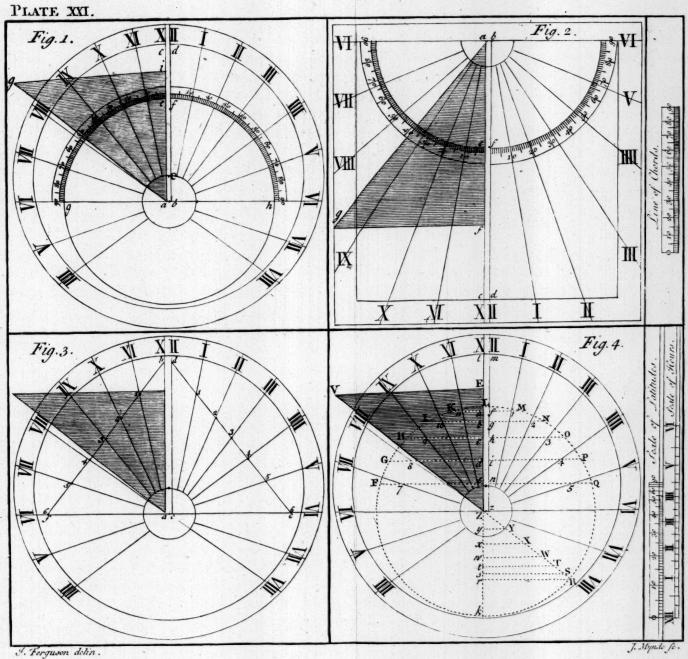
ridian will cut the horizon in the number of degrees that II is diftant from XII: and fo, by making 15 degrees of the equator pass under the brasen meridian for every hour, the first meridian of the globe will cut the horizon in the distances of all the hours from XII to VI, which is just 90 degrees; and then you need go no farther, for the distances of XI, X, IX, VIII, VII, and VI, in the forenoon, are the fame from XII, as the distances of I, II, III, IV, V. and VI, in the afternoon: and these hour-lines continued through the center, will give the opposite hour-lines on the other half of the dial: but no more of these lines need be drawn, than what answer to the fun's continuance above the horizon of your place on the longest day, which may be eafily found by the 26th problem of the foregoing lecture.

Thus, to make a horizontal dial for the latitude of London, which is 51½ degrees north, elevate the north pole of the globe 51½ degrees above the north point of the horizon, and then turn the globe, until the first meridian (which is that of London on the English terrestrial globe) cuts the north point of the horizon, and

fet the hour-index to XII at noon.

Then, turning the globe westward until the index points successively to I, II, III, IV, V, and VI, in the afternoon; or until 15, 30, 45, 60, 75, and 90 degrees of the equator pass under the brasen meridian, you will find that the first meridian of the globe cuts the horizon in the following numbers of degrees from the north toward the east, viz. 11\frac{2}{3} 24\frac{1}{4}, 38\frac{1}{12}, 53\frac{1}{2}, 71\frac{1}{15}, and 90; which are the respective distances of the above hours from XII upon the plane of the horizon.





To transfer these, and the rest of the hours, Plate to a horizontal plane, draw the parallel right Fig. 1. lines ac and bd upon that plane, as far from each other as is equal to the intended thickness of the gnomon or stile of the dial, and the space included between them will be the meridian or twelve o'clock line on the dial. Cross this meridian at right angles with the fix o'clock line g b, and fetting one foot of your compasses in the intersection a, as a center, describe the quadrant ge with any convenient radius or opening of the compasses: then, setting one foot in the interfection b, as a center, with the same radius describe the quadrant f b, and divide each quadrant into 90 equal parts or degrees, as in the figure.

Because the hour-lines are less distant from each other about noon, than in any other part of the dial, it is best to have the centers of these quadrants at a little distance from the center of the dial-plane, on the side opposite to XII, in order to enlarge the hour distances thereabout under the same angles on the plane. Thus, the center of the plane is at C, but the centers of the

quadrants at a and b.

Lay a ruler over the point b (and keeping it there for the center of all the afternoon hours in the quadrant f(b)) draw the hour-line of I, through  $II^{\frac{1}{3}}$  degrees in the quadrant; the hour-line of II, through  $24^{\frac{1}{4}}$  degrees; of III, through  $38^{\frac{1}{12}}$  degrees; IIII, through  $53^{\frac{1}{2}}$ , and V through  $71^{\frac{1}{13}}$ : and because the sun rises about four in the morning, on the longest days at London, continue the hour-lines of IIII and V, in the afternoon, through the center b to the opposite side of the dial.—This done, lay the ruler to the center a, of the quadrant eg, and through the

like divisions or degrees of that quadrant, viz. 11<sup>2</sup>, 24<sup>1</sup>, 38 <sup>1</sup>, 53<sup>1</sup>, and 71<sup>1</sup>, draw the forenoon hour-lines of XI, X, IX, VIII, and VII; and because the sun sets not before eight in the evening on the longest days, continue the hour-lines of VII and VIII in the forenoon, through the center a, to VII and VIII in the afternoon; and all the hour-lines will be finished on this dial; to which the hours may be set, as in the figure.

Lastly, through  $51\frac{1}{2}$  degrees of either quadrant, and from its center draw the right line ag for the hypothenuse or axis of the gnomon agi; and from g, let fall the perpendicular gi, upon the meridian line ai, and there will be a triangle made, whose sides are ag, gi, and ia. If a plate similar to this triangle be made as thick as the distance between the lines ac and bd, and set upright between them, touching at a and b, its hypothenuse ag will be parallel to the axis of the world, when the dial is truly set; and will cast a shadow on the hour of the day.

N. B. The trouble of dividing the two quadrants may be faved, if you have a scale with a line of chords upon it, such as that on the right hand of the plate; for if you extend the compasses from 0 to 60 degrees of the line of chords, and with that extent, as a radius, describe the two quadrants upon their respective centers, the above distances may be taken with the compasses upon the line, and set off upon the qua-

drants.

Fig. 2. To conftruct an erect direct fouth dial. To make an erest direct fouth dial. Elevate the pole to the co-latitude of your place, and proceed in all respects as above taught for the horizontal dial, from VI in the morning to VI in the afternoon, only the hours must be reversed, as in the figure; and the hypothenuse ag, of the gnomon

fr

gnomon agf, must make an angle with the dialplane equal to the co-latitude of the place. As the sun can shine no longer on this dial, than from six in the morning until six in the evening, there is no occasion for having any more than

twelve hours upon it.

To make an erect dial, declining from the fouth To contoward the east or west. Elevate the pole to the fruct an latitude of your place, and screw the quadrant of erect dealtitude to the zenith. Then, if your dial de-dial. clines toward the east (which we shall suppose it to do at present) count in the horizon the degrees of declination, from the east point toward the north, and bring the lower end of the quadrant to that degree of declination at which the reckoning ends. This done, bring any particular meridian of your globe (as suppose the first meridian) directly under the graduated edge of the upper part of the brasen meridian, and fet the hour-index to XII at noon. Then, keeping the quadrant of altitude at the degree of declination in the horizon, turn the globe eaftward on its axis, and observe the degrees cut by the first meridian in the quadrant of altitude (counted from the zenith) as the hour-index comes to XI, X, IX, &c. in the forenoon, or as 15, 30, 45, &c. degrees of the equator pass under the brafen meridian at these hours respectively; and the degrees then cut in the quadrant by the first meridian, are the respective distances of the forenoon hours from XII on the plane of the dial.—Then, for the afternoon hours, turn the quadrant of altitude round the zenith until it comes to the degree in the horizon opposite to that where it was placed before; namely, as far from the west point of the horizon toward the fouth, as it was fet at first from the east point to-Y 2 ward

ward the north; and turn the globe westward on its axis, until the first meridian comes to the brasen meridian again, and the hour-index to XII: then, continue to turn the globe westward, and as the index points to the afternoon hours I, II, III, &c. or at 15, 30, 45, &c. degrees of the equator pass under the brasen meridian, the first meridian will cut the quadrant of altitude in the respective number of degrees from the zenith, that each of these hours is from XII on the dial.—And note, that when the first meridian goes off the quadrant at the horizon, in the forenoon, the hour-index shews the time when the fun will come upon this dial: and when it goes off the quadrant in the afternoon, the index will point to the time when the fun goes off the dial.

Having thus found all the hour-distances from XII, lay them down upon your dial-plate, either by dividing a semicircle into two quadrants of 90 degrees each (beginning at the hour-line of XII) or by the line of chords, as above directed.

In all declining dials, the line on which the stile or gnomon stands (commonly called the substile-line) makes an angle with the twelve o'clock line, and falls among the forenoon hour-lines, if the dial declines toward the east; and among the afternoon hour-lines, when the dial declines toward the west; that is, to the lest hand from the twelve o'clock line in the former case, and to the right hand from it in the latter.

To find the distance of the substile from the twelve o'clock line; if your dial declines from the fouth toward the east, count the degrees of that declination in the horizon from the east point toward the north, and bring the lower end of the quadrant of altitude to that degree of

declination

declination where the reckoning ends: then turn the globe until the first meridian cuts the horizon in the like number of degrees, counted from the south point toward the east; and the quadrant and first meridian will then cross one another at right angles, and the number of degrees of the quadrant, which are intercepted between the first meridian and the zenith, is equal to the distance of the substile-line from the twelve o'clock line; and the number of degrees of the first meridian, which are intercepted between the quadrant and the north pole, is equal to the elevation of the stile above the plane of the dial.

If the dial declines westward from the south, count that declination from the east point of the horizon toward the south, and bring the quadrant of altitude to the degree in the horizon at which the reckoning ends; both for finding the forenoon hours, and the distance of the substile from the meridian: and for the afternoon hours, bring the quadrant to the opposite degree in the horizon, namely, as far from the west toward the north, and then proceed in all respects as above.

Thus, we have finished our declining dial: and in so doing, we made four dials, viz.

1. A north dial, declining eastward by the fame number of degrees. 2. A north dial, declining the fame number west. 3. A south dial, declining east. And, 4. A south dial, declining west. Only, placing the proper number of hours, and the stile or gnomon respectively, upon each plane. For (as above-mentioned) in the south-west plane, the substile-line falls among the afternoon hours; and in the south-east, of the same declination among the forenoon Y 3

hours, at equal distances from XII. And so, all the morning hours on the west decliner will be like the afternoon hours on the east decliner; the south-east decliner will produce the north-west decliner; and the south west decliner, the north-east decliner, by only extending the hourlines, stile and substile, quite through the center: the axis of the stile (or edge that casts the shadow on the hour of the day) being in all dials whatever parallel to the axis of the world, and consequently pointing toward the north pole of the heaven in north latitudes, and toward the south pole, in south latitudes. See more of this in the following lecture.

An eafy method for conftructing of dials. But because every one who would like to make a dial, may perhaps not be provided with a globe to affish him, and may probably not understand the method of doing it by logarithmic calculation; we shall shew how to perform it by the plain dialling lines, or scale of latitudes and hours; such as those on the right hand of Fig. 4. in Plate XXI, or at the top of Plate XXII, and which may be had on scales commonly sold by the mathematical instrument-makers.

This is the easiest of all mechanical methods, and by much the best, when the lines are truly divided: not only the half hours and quarters may be laid down by all of them, but every fifth minute by most, and every fingle minute by those where the line of hours is a fact in length

where the line of hours is a foot in length.

Fig. 3.

Having drawn your double meridian line ab, cd, on the plane intended for a horizontal dial, and croffed it at right angles by the fix o'clock line fe (as in Fig. 1.) take the latitude of your place with the compasses, in the scale of latitudes, and fer that extent from c to e, and from a to f, on the six o'clock line: then, taking the whole six hours

hours between the points of the compasses in the scale of hours, with that extent set one foot in the point e, and let the other foot fall where it will upon the meridian line cd, as at d. Do the fame from f to b, and draw the right lines ed and fb, each of which will be equal in length to the whole scale of hours. This done, fetting one foot of the compasses in the beginning of the scale at XII, and extending the other to each hour on the scale, lay off these extents from d to e for the afternoon hours, and from b to f for those of the forenoon: this will divide the lines de and bf in the fame manner as the hour-scale is divided, at 1, 2, 3, 4, 5, and 6; on which the quarters may also be laid down, if required. Then, laying a ruler on the point c, draw the first five hours in the afternoon, from that point, through the dots at the numeral figures 1, 2, 3, 4, 5, on the line de; and continue the lines of IIII and V through the center c to the other fide of the dial, for the like hours of the morning; which done, lay the ruler on the point a, and draw the last five hours in the forenoon through the dots 5, 4, 3, 2, 1, on the line fb; continuing the hour-lines of VII and VIII through the center a to the other fide of the dial, for the like hours of the evening; and fet the hours to their respective lines as in the figure. Laftly, make the gnomon the fame way as taught above for the horizontal dial, and the whole will be finished.

To make an erect fouth dial, take the co-latitude of your place from the scale of latitudes, and then proceed in all respects for the hour-lines, as in the horizontal dial; only reversing the hours, as in Fig. 2; and making the angle of the stile's

height equal to the co-latitude.

Y 4

I have

I have drawn out a fet of dialing lines upon the top of Plate XXII, large enough for making a dial of nine inches diameter, or more inches if required; and have drawn them tolerably exact for common practice, to every quar-This scale may be cut off from ter of a hour. the plate, and pasted upon wood, or upon the infide of one of the boards of this book; and then it will be somewhat more exact than it is on the plate, for being rightly divided upon the copperplate, and printed off on wet paper, it shrinks as the paper dries; but when it is wetted again, it stretches to the same size as when newly printed; and if pasted on while wet, it will remain of that fize afterward.

But left the young dialift should have neither globe nor wooden scale, and should tear or otherwise spoil the paper one in pasting, we shall now shew him how he may make a dial without any of these helps. Only, if he has not a line of chords, he must divide a quadrant into 90 equal parts or degrees for taking the proper angle of

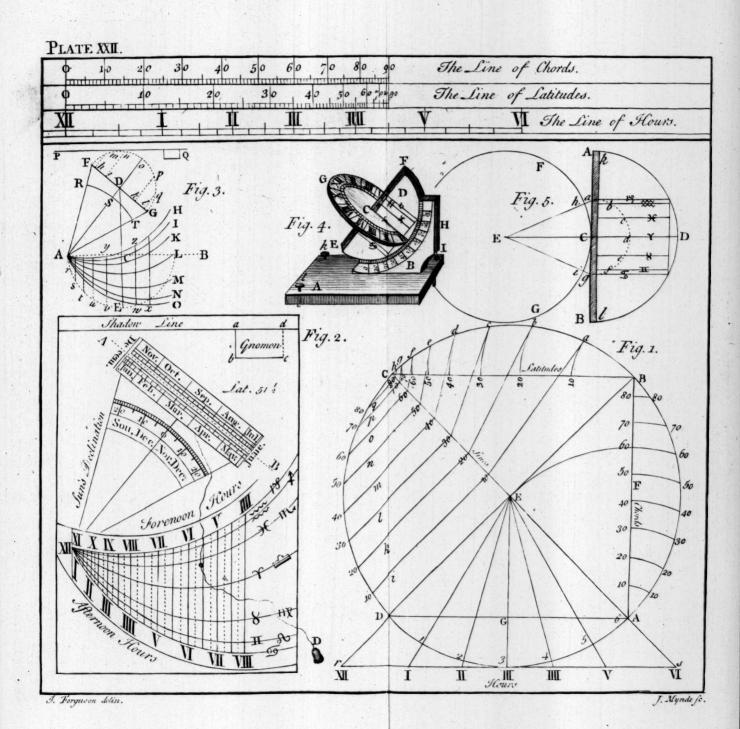
the stile's elevation, which is easily done.

Fig. 4.

Horizon-

With any opening of the compasses, as ZL, describe the two semicircles LFk and LQk, upon the centers Z and z, where the fix o'clock line crosses the double meridian line, and divide each semicircle into 12 equal parts, beginning at L; though, strictly speaking, only the quadrants from L to the fix o'clock line need be divided; then connect the divisions which are equidistant from L, by the parallel lines KM, IN, HO, GP, and FQ. Draw VZ for the hypothenuse of the stille, making the angle VZE equal to the latitude of your place; and continue the line VZ to R. Draw the line Rr parallel to the fix o'clock line, and set off the distance R from R to R, the





the distance b I from Z to X, c H from Z to W. 4G from Z to T, and eF from Z to S. Then draw the lines Ss, Tt, Ww, Xx, and Ty, each parallel to Rr. Set off the distance y T from a to 11, and from f to 1: the distance x X from b to 10, and from g to 2; w W from c to 9, and from b to 3; tT from d to 8, and from i to 4; s & from e to 7, and from n to 5. Then laying a ruler to the center Z, draw the forenoon hour lines through the points 11, 10, 9, 8, 7; and laying it to the center z, draw the afternoon lines through the points 1, 2, 3, 4, 5; continuing the forenoon lines of VII and VIII through the center Z, to the opposite side of the dial, for the like afternoon hours; and the afternoon lines IIII and V through the center z, to the opposite fide, for the like morning hours. Set the hours to these lines as in the figure, and then erect the ftile or gnomon, and the horizontal dial will be finished.

To construct a south dial, draw the line VZ, South making an angle with the meridian ZL equal to dial. the co-latitude of your place; and proceed in all respects as in the above horizontal dial for the same latitude, reversing the hours as in Fig. 2. and making the elevation of the gnomon equal to the co-latitude.

Perhaps it may not be unacceptable to explain the method of conftructing the dialing lines, and fome others; which is as follows.

With any opening of the compasses, as EA, Plate according to the intended length of the scale, XXII. describe the circle ADCB, and cross it at right angles by the diameters CEA and DEB. Fig. 1. Divide the quadrant AB first into 9 equal parts, Dialing and then each part into 10; so shall the quadrant constructs be divided into 90 equal parts or degrees. Draw ed.

the right line AFB for the chord of this quadrant, and fetting one foot of the compasses in the point A, extend the other to the several divisions of the quadrant, and transfer these divisions to the line AFB by the arcs, 10 10, 20 20, &c. and this will be a line of chords, divided into 90 unequal parts; which, if transferred from the line back again to the quadrant, will divide it equally. It is plain by the figure, that the distance from A to 60 in the line of chords, is just equal to AE, the radius of the circle from which that line is made; for if the arc 60 60 be continued, of which A is the center, it goes exactly through the center E of the arc AB.

And therefore, in laying down any number of degrees on a circle, by the line of chords, you must first open the compasses, so as to take in just 60 degrees upon that line, as from A to 60: and then, with that extent, as a radius, describe a circle which will be exactly of the same size with that from which the line was divided: which done, set one foot of the compasses in the beginning of the chord line, as at A, and extend

the other to the number of degrees you want upon the line, which extent, applied to the circle, will include the like number of degrees upon

it.

Divide the quadrant CD into 90 equal parts, and from each point of division draw right lines as ikl, &c. to the line CE; all perpendicular to that line, and parallel to DE, which will divide EC into a line of sines; and although these are seldom put among the dialing lines on a scale, yet they affish in drawing the line of latitudes. For, if a ruler be laid upon the point D, and over each division in the line of sines, it will divide the quadrant CB into 90 unequal parts,

as Ba, ab, &c. shewn by the right lines 10 a, 20 b, 30 c, &c. drawn along the edge of the ruler. If the right line BC be drawn, subtending this quadrant, and the nearest distances Ba, Bb, Cc, &c. be taken in the compasses from B, and set upon this line in the same manner as directed for the line of chords, it will make a line of latitudes BC, equal in length to the line of chords AB, and of an equal number of divisions, but very

unequal as to their lengths.

Draw the right line DGA, fubtending the quadrant DA; and parallel to it, draw the right line rs, touching the quadrant DA at the numeral figure 3. Divide this quadrant into fix equal parts, as 1, 2, 3, &c. and through these points of division draw right lines from the center E to the line rs, which will divide it at the points where the fix hours are to be placed, as in the figure. If every fixth part of the quadrant be subdivided into four equal parts, right lines drawn from the center through these points of division, and continued to the line rs, will divide each hour upon it into quarters.

In Fig. 2. we have the representation of a A dial on portable dial, which may be easily drawn on a a card. card, and carried in a pocket-book. The lines Fig. 2. ad, ab, and bc of the gnomon must be cut quite through the card; and as the end ab of the gnomon is raised occasionally above the plane of the dial, it turns upon the uncut line cd as on a hinge. The line dotted AB must be slit quite through the card, and the thread must be put through the slit, and have a knot tied behind, to keep it from being easily drawn out. On the other end of this thread is a small plummet D, and on the middle of it a small bead for shewing the time of the day.

To rectify this dial, fet the thread in the flit right against the day of the month, and stretch the thread from the day of the month over the angular point where the curve lines meet at XII; then shift the bead to that point on the thread, and the dial will be rectified.

To find the hour of the day, raise the gnomon (no matter how much or how little) and hold the edge of the dial next the gnomon toward the sun, so as the uppermost edge of the shadow of the gnomon may just cover the shadow-line; and the bead then playing freely on the sace of the dial, by the weight of the plummet, will shew the time of the day among the hour-lines, as it is forenoon or afternoon.

To find the time of fun-rifing and fetting, move the thread among the hour-lines, until it either covers fome one of them, or lies parallel betwixt any two; and then it will cut the time of fun-rifing among the forenoon hours, and of fun-fetting among the afternoon hours, on that day of the year for which the thread is fet in the fcale of months.

To find the fun's declination, stretch the thread from the day of the month over the angular point at XII, and it will cut the fun's declination, as it is north or fouth, for that day, in the arched scale of north and south declination.

To find on what days the fun enters the figns: when the bead, as above rectified, moves along any of the curve lines which have the figns of the zodiac marked upon them, the fun enters those figns on the days pointed out by the thread in the scale of months.

The construction of this dial is very easy, especially if the reader compares it all along with

with Fig. 3. as he reads the following explana-

tion of that figure.

Draw the occult line AB parallel to the top of Fig. 3. the card, and cross it at right angles with the six o'clock line ECD; then upon C, as a center, with the radius CA, describe the semicircle AEL, and divide it into 12 equal parts (beginning at A) as Ar, As, &c. and from these points of division, draw the hour lines r, s, t, u, v, E, w, and x, all parallel to the fix o'clock line EC. If each part of the semicircle be divided into four equal parts, they will give the half-hour lines and quarters, as in Fig. 2. Draw the right line  $ASD_0$ , making the angle SAB equal to the latitude of your place. Upon the center A describe the arch RST, and set off upon it the arcs SR and ST, each equal to  $23\frac{1}{2}$  degrees, for the fun's greatest declination; and divide them into 231 equal parts, as in Fig. 2. Through the interfection D of the lines ECD and ADo, draw the right line FDG at right angles to ADo. Lay a ruler to the points A and R, and draw the line ARF through 231 degrees of fouth declination in the arc SR; and then laying the ruler to the points A and T, draw the line ATG through 231 degrees of north declination in the arc ST: so shall the lines ARF and ATG cut the line FDG in the proper length for the scale of months. Upon the center D, with the radius DF, describe the semicircle FoG; and divide it into fix equal parts, Fm, mn, no, &c. and from these points of division draw the right lines mb, ni, pk, and ql, each parallel to o D. Then fetting one foot of the compasses in the point F, extend the other to A, and describe the arc AzH for the tropic of w: with the same extent, fetting one foot in G, defcribe

fcribe the arc AEO for the tropic of . Next fetting one foot in the point b, and extending the other to A, describe the arc ACI for the beginnings of the figns = and t; and with the same extent, fetting one foot in the point I, describe the arc AN for the beginnings of the figns  $\pi$  and  $\Omega$ . Set one foot in the point i, and having extended the other to A, describe the arc AK for the beginnings of the figns x and m; and with the fame extent, fet one foot in k, and describe the arc AM for the beginnings of the figns 8 and m. Then, fetting one foot in the point D, and extending the other to A, describe the curve AL for the beginnings of \( \psi \) and \( \tilde{\psi} \); and the figns will be finished. This done, lay a ruler from the point A over the fun's declination in the arch RST (found by the following table) for every fifth day of the year; and where the ruler cuts the line FDG, make marks; and place the days of the months right against these marks, in the manner shewn by Fig. 2. Lastly, draw the shadow line P 2 parallel to the occult line AB; make the gnomon, and fet the hours to their respective lines, as in Fig. 2. and the dial will be finished.

Fig. 4.

An universal dial, There are several kinds of dials, which are called universal, because they serve for all latitudes. Of these, the best one that I know, is Mr. Pardie's, which consists of three principal parts: the first whereof is called the borizontal plane (A) because in the practice it must be parallel to the horizon. In this plane is fixt an upright pin, which enters into the edge of the second part BD, called the meridional plane; which is made of two pieces, the lowest whereof (B) is called the quadrant, because it contains a quarter of a circle, divided into 90 degrees; and

it is only into this part, near B, that the pin enters. The other piece is a semicircle (D) adjusted to the quadrant, and turning in it by a groove, for raising or depressing the diameter (EF) of the semicircle, which diameter is called the axis of the inftru-The third piece is a circle (G) divided on both fides into 24 equal parts, which are the hours. This circle is put upon the meridional plane so, that the axis (EF) may be perpendicular to the circle; and the point C be the common center of the circle, semicircle, and qua-The straight edge of the semicircle is chamfered on both fides to a fharp edge, which passes through the center of the circle. On one fide of the chamfered part, the first fix months of the year are laid down, according to the fun's declination for their respective days, and on the other fide the last fix months. And against the days on which the fun enters the figns, there are straight lines drawn upon the semicircle, with the characters of the figns marked upon them. There is a black line drawn along the middle of the upright edge of the quadrant, over which hangs a thread (H) with its plummet (I) for levelling the instrument. N. B. From the 22d of September to the 20th of March, the upper furface of the circle must touch both the center C of the semicircle, and the line of r and a; and from the 20th of March to the 22d of September, the lower furface of the circle must touch that center and line.

To find the time of the day by this dial. Having fet it on a level place in fun-shine, and adjusted it by the levelling screws k and l, until the plumb line hangs over the back line upon the edge of the quadrant, and parallel to the said edge; move the semicircle in the quadrant, until

the line of  $\varphi$  and  $\triangle$  (where the circle touches) comes to the latitude of your place in the quadrant: then, turn the whole meridional plane BD, with its circle G, upon the horizontal plane A, until the edge of the shadow of the circle falls precisely on the day of the month in the semicircle; and then, the meridional plane will be due north and south, the axis EF will be parallel to the axis of the world, and will cast a shadow upon the true time of the day, among the hours on the circle.

N. B. As, when the instrument is thus rectified, the quadrant and semicircle are in the plane of the meridian, fo the circle is then in the plane of the equinoctial. Therefore, as the fun is above the equinoctial in fummer (in northern latitudes) and below it in winter; the axis of the femicircle will cast a shadow on the hour of the day, on the upper furface of the circle, from the 20th of March to the 22d of September: and from the 22d of September, to the 20th of March, the hour of the day will be determined by the fhadow of the semicircle, upon the lower surface of the circle. In the former case, the shadow of the circle falls upon the day of the month, on the lower part of the diameter of the semicircle; and in the latter case on the upper part.

The method of laying down the months and figns upon the semicircle, is as follows. Draw the right line ACB, equal to the diameter of the semicircle ADB, and cross it in the middle at right angles with the line ECD, equal in length to ADB; then EC will be the radius of the circle FCG, which is the same as that of the semicircle. Upon E, as a center, describe the circle FCG, on which set off the arcs Cb and Ci, each equal to  $23\frac{1}{2}$  degrees, and divide them accordingly into that number for the sun's declination

Fig. 5.

clination. Then, laying the edge of a ruler over the center E, and also over the fun's declination for every fifth day \* of each month (as in the card dial) mark the points on the diameter AB of the semicircle from a to g, which are cut by the ruler; and there place the days of the months accordingly, answering the fun's declination. This done, fetting one foot of the compasses in C, and extending the other to a or g, describe the semicircle a b c d e f g; which divide into fix equal parts, and through the points of division draw right lines, parallel to CD, for the beginning of the figns (of which one half are on one fide of the femicircle, and the other half on the other fide) and fet the characters of the figns to their proper lines, as in the figure.

The following table shews the sun's place and declination, in degrees and minutes, at the noon of every day of the second year after leap year; which is a mean between those of leap year itself, and the first and third years after. It is useful for inscribing the months and their days on sun-dials; and also for finding the latitudes of places, according to the methods prescribed

after the table.

<sup>\*</sup> The intermediate days may be drawn in by hand, if the spaces be large enough to contain them.

	AT	able	shewin	g the	fun	's p	lace a	and d	eclinat	ion.
		4	uary.		1	1		Febr	uary.	
1	Sun	's Pl.	Sun's	Dec.		E	Sun	's Pl.	Sun's	Dec.
Lays.	D.	M.	D.	ίVI.		ays.	D.	M.	Sun's	IVI.
1	III	~	23	5 1		1				S 2
1	2 12	6	22	55		2	13	39		45
1.	3 13	8		49		3	14	40		27
	4 14	9	22	43		4	15	41		10
1.	5 15	10	22	37		5	16	41	1	51
1	5 16	11	22	29		6	17	42	-	33
1:	7 17	12		22		7	18	43		14
1 8	818	13		14		8	19	43	1	55
19	19	14		5 56		9	20	44	14	36
-	20	16	21	56		I C	2.1	45	14	17
11		17	21	47		11	22	45	13	57
12		18	21	37		12	23	46	13	37
13		19	21	27	1	13	24	46	13	17
14		20	21	17	1	4	25	47	12	57
15		21	21	6	1	5	26	47	12	36
16	1	22	20	54			27	48	12	15
17	27	24	20	43	1	7	28	48	II	54
18	28	25	20	30	1	8	29	48	11	33
19		26	20	18	. 1	9	0%	49	II	12
20	0.20		20	5	2	C	I	45	10	50
21	I	28	19	52			2	5C	10	29
22	2	29	19	38		2	3	50	10	7
23	3	30	19	24	2	3	4	50	9	45
24		31	19	10		+	.5	51	9	23
25	5	32	18	55	2	5	6	51	9	0
26		33	18	4C	2	6	7	51	8	38
27	7	34	18	24	2		8	51	8	16
28		35	18	5		8	9	51)	7	53
29	9	35	17	53	11	nt	hete	tabl	es N (	ig-
30	10	36	17	36	In these tables N sig- nisses north declina-					
31	11	371	17	19		tie	n, a	nd S	S fout	h.
	100	- 100	G. P. L.						Δ ′	Table

A Table

	A Table shewing the fun's place and declination.									
-	March.					April.				
0	Sun	's Pl,	Sun's	Dec.		U	Sun'	s Pl.	Sun's	Dec.
Days.	D.	. M.	D.	M.		Days.	D.	M.	D.	M.
1	10	¥ 52	7	5 30		1	110		41	N 36
2	11	52	7 6	7		2	12	37		59
3	12	52	6	7 44		3 4	13	37 36	5	59 22
4	13	52	6	21				35	4 5 5 6	45
5	14	52 52	5_	50		5	15	34		
6	15	52 51 51 51 51	5 5 4	35 12 48				33 31 30	6	31 53 16
7 8		51	5	12		7 8	17	31	6	53
	17	51		48			18	30	7 7 8	16
9	18	51	4	25		10	19	29 28	7	38
11 6	19	51	4	2		10	20			0
	20	51 50 50	3	38		11	21	27	8	22
12 13 14	21	50	3	14		12	22	25		41
13	22	50	2	5 I 27		13	23	24	9	6
14	23	50	2			14	24	23	9	28
15	24	49	2_	4		15	25	21	9	49
16	25	49 48 48	I	40 16		16	26	20	10	32
17 18	26	48	1	It		17	27	18	10	32
18	27	48	0	53		18	28	17	10	53
19 20	28	48	0	29	1	19	29	15	II .	14
	29	47	0	5		2€. 21	-			34
21	0	47	01		-		I	12	11	55 15 35
22	I	46	0	42		22	2	11	12	15
23	2	45	I			23 24	3 4	5	12	35
24	3	45 44	ĭ	29		25	5	7 6	13	5:
25 25	4	44		53		20	6			2
	5	43	2 2	17	- 1	27	7	4 2	13	3+ 53 12
27 28		42		40		28	3	0	13	2.
29	7 8	42	3	3 27		29	8	59	14	3
20	9	41	3		1	30	9	57	14	49
30	10	40	4	50 13 Z		3		3/		
311	10	39	4	131		- 1				-1
				Z	2				A	Table

A Table shewing the s						s pla	ace a			on.
	May.					June.				
D	Sun's Pl. Sun's Dec.				D			Sun's		
Days.	D.	. M.	D	M.		Days.	D.	M.		M.
1	10	8 55	15	N 7		1	10	и 44	221	N 5
2	II	53	15	25		2	II	41		13
3	12	51	15	43		3	12	39	22	21
4		49	16	0		4	13	36	22	28
5	14	47	16	18		_5	14	34	22	35
	15	45	16	35		6	15	31	22	41
7	16	43	16	51		7 8	16	28		47
8	17	41	17	8			17	26	The North Control	53
9	18	39	17	24		9	18	23	22	58
10	19	_36	17	40		10	19	20	23	3 7 11 15 18
11	20	34	17	55		11	20	18	_	7
12	21	32	18	10		12	21	15	23	11
13	22	30	18	25		13	22	12	23	15
14	23	28	18	40		14	23	. 9	23	
15	24	25	18	54		15	24	7	23	20
16	25	23	19	8		10	25	4	23	22
17	26	21	19	22		17	26 26	- 11	23	24
18	27 28	19 16	19	35		18	1	58	23	26
19	11	14	19	48		19 20	27 28	56	23	27 28
20	29					-		53	23	28
21		100	20	13		2I 22	29	50 2547	23	28
22	1 2	9	20 20	25		23	1	45	23 23	28
23 24	3	4	20	37 48		24	2	42	23	27
	4	2	20	59			3	39	23	26
$\frac{25}{26}$	4	59	21	10		25 26	4	36	23	24
27		57	21	20		27		33	23	21
28	5	54	21	30		28	5	31	23	19
29		52	21	39		29		28	23	16
30	7 8	49	21	49		3	7 8	25	23	12
30 31	9	47	21	57						

A Table

1	A Ta	ble sh	ewing	the f	fun's place and declination.						
-	July.					August.					
0	Sun's	Pl.	Sun's	Dec.		Sun's Pl.			Sun's Dec.		
Days.		M.	D.	М.		Days.		M.	D.	M.	
1	9-	22	23]	N 8		I	83	- 1	18]	N 2	
2	10	19	23	4		2	9	55	17	47	
3	11.	16	23	C		3	10	53	17	32	
4	12	14	22	55		4	II	50	17	16	
5	13	II	22	49		5 6	12	48	17_	0	
6	14	8	22	43		6	13	4	16	43	
7	15	5	22	37		7 8	14	43	16	26	
8	16	0	22	30			15	41	16	9	
9	17	2	22	23		9	16	38	15	52	
10	17	57	22	16		10	17	36	15	25	
11	18	54	22	8		11	18	33	15	17	
12	19	51	22	0	*	12	19	31	1.4	59	
13	20	49	21	52		13	20	29	14	41	
14	21	46	21	43		14	21	26	14	23	
15	22	43	2 I	33		15	22	24	14	4	
16	23	40	2 I	22		16	23	22	13	45	
17	24	38	21	14		17	24	20	13	26	
18	25	35	2 I	3		18	25	17	1.3	27	
19	26	32	20	52	-	19	26	15	12	47	
20	27	29	20	41		20	-7	1,3	12	27	
21	28	27	20	30		21	28	11	12	7	
22	29	24	20	. I 8		22	29	9	II	47	
23	08	21	20	6		23	7 = 1	7 7	11	27	
24	I	19	19	54		24	I	5	II	6	
25	2	16	19	4		25	2	_3	10	46	
26	3	13	19	28		26	3	1	10	25	
27	4	II	19	14		27	3	59	10	4	
28	5	8	19	I		28		57	9	43	
29		6	18	46		29		55	9	21	
30	7	3	18	32		30	6	53	9	0	
31	8	0	18	17		31	7	51	8	38	

Z 3

A Table

A Table shewing the so				i		Étob			
		2	Sun's	Dec	=		's Pl.		Dec
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1	8 1	<b>12</b> 49	18	V 16	1	8		3	5 14
2	9	47	7	55	2	9	7	3	37
3	10	46	7	33	3	10	7	4	
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4 5	12	42	7 6	48		12	5	4	4
6	13	40	6	26	5	13	4	5 5 5 6 6	
	14	39	6			14	4	5	3. 50
7 8		37		3 41	7 8	15	3	5	5
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9	17	37 35 34	4	55	10	17	2	6	4
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	20	29	3	9 46		20	0	7	5
14	21	28	3	23	14	21	c	7 8	1:
13 14 15 16 17 18	22	26	4 3 3 3	23 0 37	13 14 15	2 I 22	0	8	2 5 1 3
16	23	25	2	37	10	23	C	8	57
17	24	24	2	14	17 18	23	59	9	1
18	25	22	1	50	18	24	59	9	4
19	26	21	I	27	19	25	58	9	
20	27	20	I	4	20	26	59 59 58 58	10	2
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22	29	17	0	17	22	28	58 58 758	11	7
23	04	≥ 16	oS	6	23	29	58	11	28
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27	4	12	1	40	27	3	58	12	5
27 28	5	11	2	4	28	4	58	13	I
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						un's place and declination.					
1	V	lover				1			nber		
E	Sun	's Pl.	Sun's	Dec.	110	0	Sun	's P!.	Sun's	Dec.	
Days.		M.	D.			Days.	D.	M.	D.	M.	
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5 6	12	59	15	45		5	13	20	22	26	
	13	59	16	3		6	14	2 I	22	33	
7 8	15	0	16	21		7 8	15	22	22	40	
	16	0	16	.39			16	23	22	46	
9	17	0	16	56		9	17	24	22	52	
10	18	I	17	13		10	18	25	22	58	
11	19	1	17	30	-	11	19	20	23	8	
12	20	2	17	46		12	20	27	23	8	
13	21	2	18	18		13	21	28	23	12	
14	22	3	18	18		14	2.2	25	23	15	
15	23	4	18	34		15	23	.30	23	18	
16	24	4	18	49		16	24	31	23	21	
17	25		19	4		17	25	33	23	24	
18	26	5 6	19	4 18		18	26	34	23	26	
19	27	2 15 9	19	32		19	-7	35	23	/27	
20	28	7	19.	46		20	28	36	23	25	
21	29	. 7	19	59		21	29	37	23	28	
22	0	1 8	20	12		22	ov	3	23	28	
23	1	9	20	25		23	1	40	23	28	
24	2	10	20	37		24	2	4.1	23	27	
25 26	3	11	20	49		25	3	42	23	25	
26	4	11	21	1	-	26	4	-1.	23	23	
27 28	5	12	21	12		27	5	4	23	21	
28		13	21	23		27 28		4	23	18	
29	7 8	14	21	33		29	7 8	47	23	15	
30	8	15	21	43		30	8	48	23	11	
						31	9	49	23	6	

To find the latitude of any place by observation.

The latitude of any place is equal to the elevation of the pole above the horizon of that place. Therefore it is plain, that if a star was fixt in the pole, there would be nothing required to find the latitude, but to take the altitude of that star with a good instrument. But although there is no star in the pole, yet the latitude may be found by taking the greatest and least altitude of any star that never sets: for if half the difference between these altitudes be added to the least altitude, or subtracted from the greatest, the sum or remainder will be equal to the altitude of the pole at the place of observation.

But because the length of the night must be more than 12 hours, in order to have two such observations; the sun's meridian altitude and declination are generally made use of for sinding the latitude, by means of its complement, which is equal to the elevation of the equinoctial above the horizon; and if this complement be subtracted from 90 degrees, the remainder will be the latitude, concerning which, I think, the following rules take in all the various cases.

1. If the fun has north declination, and is on the meridian, and to the fouth of your place, fubtract the declination from the meridian altitude (taken by a good quadrant) and the remainder will be the height of the equinoctial or complement of the latitude north.

### EXAMPLE.

Suppose { The fun's meridian altitude 42° 20' South And his declination, fubt. 10 15 North

Rem. the complement of the lat. 32 5 Which subtract from — 90 0

And the remainder is the latitude 57 55 North

2. If the fun has fouth declination, and is fouthward of your place at noon, add the declination to the meridian altitude; the fum, if less than 90 degrees, is the complement of the latitude north: but if the sum exceeds 90 degrees, the latitude is south; and if 90 be taken from that sum, the remainder will be the latitude.

## EXAMPLES.

The fun's meridian altitude The fun's declination, add			South South
Complement of the latitude Subtract from — —	80 90	40	
Remains the latitude	9	20	North .
The fun's meridian altitude The fun's declination, add			South South
The fum is From which fubtract	100	50	
Remains the latitude —	10	50	South 3. If

3. If the sun has north declination, and is on the meridian north of your place, add the declination to the north meridian altitude; the sum, if less than 90 degrees, is the complement of the latitude south: but if the sum is more than 90 degrees, subtract 90 from it, and the remainder is the latitude north.

### EXAMPLES.

Sun's meridian altitude Sun's declination, add	60° 30' North 20. 10 North
Complement of the latitude Subtract from	80 40 90 0
Remains the latitude —	9 20 South
Sun's meridian altitude Sun's declination, add	70° 20' North 23 20 North
The fum is From which fubtract	93 40 90 0
Remains the latitude —	3 40 North

4. If the fun has fouth declination, and is north of your place at noon, fubtract the declination from the north meridian altitude, and the remainder is the complement of the latitude fouth.

## EXAMPLE.

32	20	
90	0	
	32	•

And the remainder is the latitude 57 40 South

5. If the fun has no declination, and is fouth of your place at noon, the meridian altitude is the complement of the latitude north: but if the fun be then north of your place, his meridian altitude is the complement of the latitude fouth.

# EXAMPLES.

Sun's meridian altitude Subtract from —	38° 30′ South
Remains the latitude —	51 30 North
Sun's meridian altitude Subtract from —	38° 30′ North 90 0
Remains the latitude —	51 30 South

6. If you observe the sun beneath the pole, subtract his declination from 90 degrees, and add the remainder to his altitude; and the sum is the latitude.

#### EXAMPLE.

Sun's declination — Subtract from —	20° 90	30'
Remains ————————————————————————————————————	69 de 10	30 add
The fum is the latitude	79	50

Which is north or fouth, according as the fun's declination is north or fouth: for when the fun has fouth declination, he is never feen below the north pole; nor is he ever feen below the fouth pole, when his declination is north.

7. If the fun be in the zenith at noon, and at the fame time has no declination, you are then under the equinocial, and so have no lati-

tude.

8. If the fun be in the zenith at noon, and has declination, the declination is equal to the latitude, north or fouth. These two cases are so plain, that they require no examples.

### LECT. XI.

## Of Dialing.

AVING shewn in the preceding Lecture how to make fun-dials by the assistance of a good globe, or of a dialing scale, we shall now proceed to the method of constructing dials arithmetically; which will be more agreeable to those who have learnt the elements of trigo-

trigonometry, because globes and scales can never be so accurate as the logarithms, in finding the angular distances of the hours. Yet, as a globe may be sound exact enough for some other requisites in dialing, we shall take it in oc-

casionally.

The construction of fun-dials on all planes whatever, may be included in one general rule: intelligible, if that of a horizontal dial for any given latitude be well understood. For there is no plane, however obliquely fituated with refpect to any given place, but what is parallel to the horizon of some other place; and therefore, if we can find that other place by a problem on the terrestrial globe, or by a trigonometrical calculation, and conftruct a horizontal dial for it; that dial, applied to the plane where it is to ferve, will be a true dial for that place.—Thus, an erect direct fouth dial in 511 degrees north latitude, would be a horizontal dial on the fame meridian, 90 degrees fouthward of 511 degrees north latitude; which falls in with 381 degrees of fouth latitude; but if the upright plane declines from facing the fouth at the given place, it would still be a horizontal plane 90 degrees from that place; but for a different longitude: which would alter the reckoning of the hours accordingly.

### CASE I.

1. Let us suppose that an upright plane at London declines 36 degrees westward from facing the south; and that it is required to find a place on the globe, to whose horizon the said plane is parallel; and also the difference of longitude between London and that place.

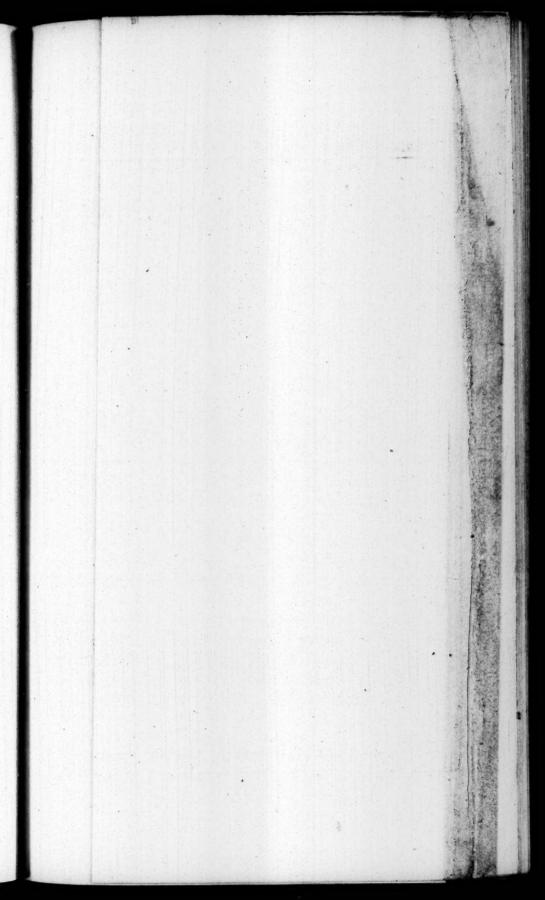
Rectify

Rectify the globe to the latitude of London, and bring London to the zenith under the brass meridian, then that point of the globe which lies in the horizon at the given degree of declination (counted westward from the south point of the horizon) is the place at which the above-mentioned plane would be horizontal.—Now, to find the latitude and longitude of that place, keep your eye upon the place, and turn the globe eastward, until it comes under the graduated edge of the brass meridian; then, the degree of the brass meridian that stands directly over the place, is its latitude; and the number of degrees in the equator, which are intercepted between the meridian of London and the brass meridian, is the

place's difference of longitude.

Thus, as the latitude of London is 513 degrees north, and the declination of the place is 36 degrees west; I elevate the north pole 511 degrees above the horizon, and turn the globe until London comes to the zenith, or under the graduated edge of the meridian; then, I count 36 degrees on the horizon westward from the fouth point, and make a mark on that place of the globe over which the reckoning ends, and bringing the mark under the graduated edge of the brass meridian, I find it to be under 301 degrees in fouth latitude: keeping it there, I count in the equator the number of degrees between the meridian of London and the brasen meridian (which now becomes the meridian of the required place) and find it to be 423. Therefore an upright plane at London, declining 36 degrees westward from the south, would be a horizontal plane at that place, whose latitude is 301 degrees fouth of the equator, and longitude 422 degrees west of the meridian of London.

Which



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Which difference of longitude being converted

into time, is 2 hours 51 minutes.

The vertical dial declining westward 36 degrees at London, is therefore to be drawn in all respects as a horizontal dial for south latitude 301 degrees; fave only, that the reckoning of the hours is to anticipate the reckoning on the horizontal dial, by 2 hours 51 minutes: for fo much fooner will the fun come to the meridian of London, than to the meridian of any place whose longitude is 423 degrees west from Lon-

2. But to be more exact than the globe will flew us, we shall use a little trigonometry.

Let NESW be the horizon of London, Plate whose zenith is Z, and P the north pole of the XXIII. fphere; and let Zb be the position of a vertical Fig. 1. plane at Z, declining westward from S (the fouth) by an angle of 36 degrees; on which plane an erect dial for London at Z is to be described. Make the semidiameter ZD perpendicular to Zh, and it will cut the horizon in D, 36 degrees west of the south S. Then, a plane in the tangent HD, touching the sphere in D, will be parallel to the plane Zb; and the axis of the fphere will be equally inclined to both these planes.

Let  $W \mathcal{D} E$  be the equinoctial, whose elevation above the horizon of Z (London) is  $38\frac{1}{2}$ degrees; and PRD be the meridian of the place D, cutting the equinoctial in R. it is evident, that the arc RD is the latitude or the place D (where the plane Zb would be horizontal) and the arc  $R \mathcal{Q}$  is the difference of lon-

gitude of the planes Zb and DH.

In the spherical triangle WDR, the arc WD is given, for it is the complement of the plane's decli-

declination from S the fouth; which complement is 54° (viz. 90°—36°): the angle at R, in which the meridian of the place D cuts the equator, is a right angle; and the angle RWD measures the elevation of the equinoctial above the horizon of Z, namely  $38\frac{1}{2}$  degrees. Say therefore, as radius is to the co-fine of the plane's declination from the fouth, so is the co-fine of the latitude of Z to the fine of RD the latitude of D: which is of a different denomination from the latitude of Z, because Z and D are on different sides of the equator.

As radius — — — — 10.00000 To co-fine 36° o'=RQ 9.90796 So co-fine 51° 30'=QZ 9.79415

To fine  $30^{\circ}$  14'=DR (9.70211)= the latitude of D, whose horizon is parallel to the vertical plane Zb at Z.

N. B. When radius is made the first term, it may be omitted, and then, by subtracting it mentally from the sum of the other two, the operation will be shortened. Thus, in the prefent case,

To the logarithmic fine of WR=\* 54° o' 9.90796 Add the logarithmic fine of RD=+ 38° 30' 9.79415

Their fum—radius — — 9.70211 gives the fame folution as above. And we shall keep to this method in the following part of the work.

<sup>\*</sup> The co-fine of 36° o', or of RQ. † The co-fine of 51° 30', or of QZ.

To find the difference of longitude of the places D and Z, fay, as radius is to the co-fine of  $38\frac{1}{2}$  degrees, the height of the equinoctial at Z, so is the co-tangent of 36 degrees, the plane's declination, to the co-tangent of the difference of longitudes. Thus,

To the logarithmic fine of \* 51° 30′ 9.89354 Add the logarithmic tang. of † 54° 0′ 10.13874

Their fum—radius - - - 10.03228 is the nearest tangent of 47° 8' = WR; which is the co-tangent of  $42^{\circ}$  52' = RQ, the difference of longitude sought. Which difference, being reduced to time, is 2 hours  $51\frac{1}{2}$  minutes.

3. And thus having found the exact latitude and longitude of the place D, to whose horizon the vertical plane at Z is parallel, we shall proceed to the construction of a horizontal dial for the place D, whose latitude is 30° 14′ fouth; but anticipating the time at D by 2 hours 51 minutes (neglecting the  $\frac{1}{2}$  minute in practice) because D is so far westward in longitude from the meridian of London; and this will be a true vertical dial at London, declining westward 36 degrees.

Assume any right line CSL for the substile of Fig. 2, the dial, and make the angle KCP equal to the latitude of the place (viz. 30° 14') to whose horizon the plane of the dial is parallel; then CRP will be the axis of the slile, or edge that casts the shadow on the hours of the day, in the dial. This done, draw the contingent line  $E\mathcal{Q}$ , sutting the substilar line at right angles in K;

<sup>\*</sup> The co-fine of 38° 30', or of WDR.

<sup>+</sup> The co-tangent of 36°, or of DW.

and from K make KR perpendicular to the axis Then KG (= KR) being made radius. that is, equal to the chord of 60° or tangent of 45° on a good fector, take 42° 52' (the difference of longitude of the places Z and D) from the tangents, and having fet it from K to M. draw CM for the hour-line of XII. Take KN equal to the tangent of an angle less by 15 degrees than KM; that is, the tangent 27° 52'; and through the point N draw CN for the hourline of I. The tangent of 12° 52' (which is 15° less than 27° 52') fet off the same way, will give a point between K and N, through which the hour-line of II is to be drawn. gent of 2° 8' (the difference between 45° and 42° 52') placed on the other fide of CL, will determine the point through which the hour-line of III is to be drawn: to which 2° 8', if the tangent of 15° be added, it will make 17° 8'; and this fet off from K toward  $\mathcal{Q}$  on the line  $E \mathcal{Q}$ , will give the point for the hour-line of IV: and fo of the reft.-The forenoon hourlines are drawn the fame way, by the continual addition of the tangents 15°, 30°, 45°, &c. to  $42^{\circ}$  52' (=the tangent of KM) for the hours of XI, X, IX, &c. as far as necessary; that is, until there be five hours on each fide of the fub-The fixth hour, accounted from that hour or part of the hour on which the substile falls, will be always in a line perpendicular to the fubftile, and drawn through the center C.

4. In all erect dials, CM, the hour-line of XII, is perpendicular to the horizon of the place for which the dial is to ferve: for that line is the interfection of a vertical plane with the plane of the meridian of the place, both which are perpendicular to the plane of the

horizon:

horizon: and any line HO, or bo, perpendicular to CM, will be a horizontal line on the plane of the dial, along which line the hours may be numbered: and CM being fet perpendicular to the horizon, the dial will have its true

polition.

5. If the plane of the dial had declined by an equal angle toward the east, its description would have differed only in this, that the hour-line of XII would have fallen on the other fide of the fubstile CL, and the line 'HO would have a fubcontrary position to what it has in this

figure.

6. And these two dials, with the upper points of their stiles turned toward the north pole, will ferve for the other two planes parallel to them; the one declining from the north toward the east, and the other from the north toward the west, by the same quantity of angle. The like holds true of all dials in general, whatever be their declination and obliquity of their planes to the horizon.

## CASE II.

7. If the plane of the dial not only declines, Fig. 3. but also reclines, or inclines. Suppose its declination from fronting the fouth S be equal to the arc SD on the horizon; and its reclination be equal to the arc Dd of the vertical circle DZ: then it is plain, that if the quadrant of altitude ZdD, on the globe, cuts the point D in the horizon, and the reclination is counted upon the quadrant from D to d; the intersection of the hour-circle PRd, with the equinoctial WQE, will determine Rd, the latitude of the place d, Aa 2 whofe

whose horizon is parallel to the given plane Zh at Z; and R  $\mathcal{Q}$  will be the difference in longi-

tude of the planes at d and Z.

Trigonometrically thus: let a great circle pass through the three points W, d, E; and in the triangle W D d, right-angled at D, the sides W D and D d are given; and thence the angle D W d is found, and so is the hypothenuse W d. Again, the difference, or the sum, of D W d and D W R, the elevation of the equinoctial above the horizon of Z, gives the angle d W R; and the hypothenuse of the triangle W R d was just now found; whence the sides R d and W R are found, the former being the latitude of the place d, and the latter the complement of R  $\mathcal{Q}$ , the difference of longitude sought.

Thus, if the latitude of the place Z be  $52^{\circ}$  10' north; the declination SD of the plane Zb (which would be horizontal at d) be  $36^{\circ}$ , and the reclination be 15°, or equal to the arc Dd; the fourth latitude of the place d, that is, the arc Rd, will be 15° 9'; and  $R\mathcal{D}$ , the difference of the longitude,  $36^{\circ}$  2'. From these data, therefore, let the dial (Fig. 4.) be described, as

in the former example.

8. Only it is to be observed, that in the reclining or inclining dials, the horizontal line will not stand at right angles to the hour-line of XII, as in erect dials; but its position may be found as follows:

found as follows.

To the common substilar line CKL, on which the dial for the place d was described, draw the dial Crpm 12 for the place D, whose declination is the same as that of d, viz. the arc SD; and HO, perpendicular to Cm, the hourline of XII on this dial, will be a horizontal line on the dial CPRM XII. For the declination of

Fig. 4.

of both dials being the fame, the horizontal line remains parallel to itself, while the erect position of one dial is reclined or inclined with respect to the position of the other.

Or, the position of the dial may be found by applying it to its plane, fo as to mark the true hour of the day by the fun, as shewn by another dial; or by a clock, regulated by a true meri-

dian line and equation table.

9. There are feveral other things requifite in the practice of dialing; the chief of which I shall give in the form of arithmetical rules, fimple and eafy to those who have learnt the elements of trigonometry. For in practical arts of this kind, arithmetic should be used as far as it can go; and scales never trusted to, except in the final construction, where they are absolutely necessary in laying down the calculated hourdistances on the plane of the dial. though the inimitable artists of this metropolis have no occasion for such instructions, yet they may be of some use to students, and to private gentlemen who amuse themselves this way.

## RULE I.

To find the angles which the hour-lines on any dial make with the substile.

To the logarithmic fine of the given latitude, or of the stile's elevation above the plane of the dial, add the logarithmic tangent of the hour distance \* from the meridian, or from the

<sup>\*</sup> That is, of 15, 30, 45, 60, 75°, for the hours of I, II, III, IV, V in the afternoon; and XI, X, IX, VIII, VII in the forenoon.

fubstile +; and the sum minus radius will be the

logarithmic tangent of the angle fought.

For, in Fig. 2. KC is to KM in the ratio compounded of the ratio of KC to KG (=KR) and of KG to KM; which making CK the radius, 10,000000, or 10,0000, or 10 or 1, are the ratio of 10,000000, or of 10,0000, or of 10,00000, or

Thus, in a horizontal dial, for latitude 51° 30', to find the angular distance of XI in the forenoon, or I in the afternoon, from XII.

To the logarithmic fine of 51° 30′ 9.89354‡ Add the logarithmic tang. of 15° 0′ 9.42805

The fum—radius is - - 9.32159= the logarithmic tangent of 11° 50′, or of the angle which the hour-line of XI or I makes with the hour of XII.

And by computing in this manner, with the fine of the latitude, and the tangents of 30, 45, 60, and 75°, for the hours of II, III, IV, and V in the afternoon; or of X, IX, VIII, and VII in the forenoon; you will find their angular distances from XII to be 24° 18′, 38° 3′, 53° 35′, and 71° 6′: which are all that there is occasion to compute for.—And these distances may be set off from XII by a line of chords; or rather, by taking 1000 from a scale of equal parts, and setting that extent as a radius from C to XII: and then, taking 209 of

‡ In which case, the radius CK is supposed to be divided into 1000000 equal parts.

<sup>†</sup> In all horizontal dials, and erect north or fouth dials, the substile and meridian are the same; but in all declining dials, the substile line makes an angle with the meridian.

the fame parts (which, in the tables, are the natural tangent of 11° 50') and fetting them from XII to XI and to I, on the line bo, which Fig. 2. is perpendicular to CXII: and fo for the reft of the hour-lines, which in the table of natural tangents, against the above distances, are 451, 782, 1355, and 2920, of fuch equal parts from XII, as the radius CXII contains 1000. And lastly, set off 1257 (the natural tangent of 51° 30') for the angle of the stile's height, which is equal to the latitude of the place.

The reason why I prefer the use of the tabular numbers, and of a scale decimally divided, to that of the line of chords, is because there is the least chance of mistake and error in this way; and likewife, because in some cases it gives us

the advantage of a nonius' division.

In the universal ring-dial, for instance, the divisions on the axis are the tangents of the angles, of the fun's declination placed on either fide of the center. But instead of laying them down from a line of tangents, I would make a scale of equal parts, whereof 1000 should anfwer exactly to the length of the femi-axis, from the center to the infide of the equinoctial ring; and then lay down 434 of these parts toward each end from the center, which would limit all the divisions on the axis, because 434 are the natural tangent of 23° 29'. And thus by a nonius affixed to the fliding piece, and taking the fun's declination from an Epitemeris, and the tangent of that declination from the table of natural tangents, the flider might be always fet true to within two minutes of a degree.

And this scale of 434 equal parts might be placed right against the 231 degrees of the sun's declination, on the axis, instead of the fun's

Aa4

place,

place, which is there of very little use. For then, the slider might be set in the usual way, to the day of the month, for common use; but to the natural tangent of the declination, when great accuracy is required.

The like may be done wherever a scale of sines

or tangents is required on any instrument.

#### RULE II.

The latitude of the place, the sun's declination, and bis bour distance from the meridian, being given; to find (1.) bis altitude; (2.) bis azimuth.

Fig. 3,

1. Let d be the fun's place, dR, his declination: and in the triangle PZd, Pd the fum, or the difference, of dR, and the quadrant PR being given by the supposition, as also the complement of the latitude PZ, and the angle dPZ, which measures the horary distance of d from the meridian; we shall (by Case 4, of Keill's Oblique spheric Trigonometry) find the base Zd, which is the sun's distance from the zenith, or the complenent of his altitude.

And 2.) As fine Zd: fine Pd:: fine dPZ: dZP, or of its supplement DZS, the azimuthal

distance from the fouth.

Or, the practical rule may be as follows:

Write A for the fine of the fun's altitude, L and l for the fine and co-fine of the latitude, D and d for the fine and co-fine of the fun's declination, and H for the fine of the horary diftance from VI.

Then the relation of H to A will have three varieties.

I. When the declination is toward the elevated pole, and the hour of the day is between XII and VI; it is A = LD + Hld, and  $H = \frac{A - LD}{dd}$ .

2. When the hour is after VI, it is A=LD—Hld, and  $H=\frac{LD+A}{A}$ .

3. When the declination is toward the depressed pole, we have A = Hld - LD, and  $H = \frac{A + LD}{ld}$ .

Which theorems will be found useful, and expeditious enough for folving those problems in geography and dialing, which depend on the relation of the sun's altitude to the hour of the day.

## EXAMPLE I.

Suppose the latitude of the place to be 51\frac{1}{2} degrees north; the time five hours distant from XII, that is, an hour after VI in the morning, or before VI in the evening: and the sun's declination 20° north. Required the sun's altitude?

Then, to log.  $L = \log$ . fine 51° 30′ 1.89354\* add log.  $D = \log$ . fine 20° 0′ 1.53405

Their fum - 1.42759 gives LD = logarithm of 0.267664, in the natural fines.

\* Here we confider the radius as unity, and not 10,00000, by which, instead of the index 9, we have—1, as above: which is of no farther use, than making the work a little easier.

And, to log.  $H = \log$ . fine  $\dagger$  15° 0′ 1.41300 add  $\begin{cases} \log l = \log$ . fine  $\ddagger$  38° 0′ 1.79+14  $\log l$  d.  $= \log$ . fine  $\parallel$  70° 0′ 1.97300

Their fum - - - 1.18014 gives H l d = logarithm of 0.151408, in the natural fines.

And these two numbers (of 0.267664 and 0.151408) make 0.419072 = A; which, in the table, is the nearest natural sign of 24° 47′,

the fun's altitude fought.

The fame hour-distance being assumed on the other side of VI, then LD-Hld is 0.116256, the sine of 69  $40'\frac{1}{2}$ ; which is the sun's altitude at V in the morning, or VII in the evening, when his north declination is  $20^{\circ}$ .

But when the declination is 20° fouth, (or toward the depressed pole) the difference Hld-LD becomes negative, and thereby shews that, a hour before VI in the morning, or past VI in the evening, the sun's center is 6°  $40'\frac{1}{2}$  below the horizon.

### EXAMPLE II.

In the fame latitude and north declination, from the given altitude to find the hour.

Let the altitude be 48°; and because, in this case  $H = \frac{A - LD}{ld}$ , and A (the natural fine of 48°) = .743145, and LD = .267664, A-LD

<sup>+</sup> The distance of one hour from VI.

<sup>†</sup> The co-latitude of the place.

The co-declination of the fun.

will be 0.475481, whose logarithmic fine is - 1.6771331 from which taking the logarithmic fine of l + d = - 1.7671354

Remains - - 1.9099977 the logarithmic fine of the hour-distance sought, viz. of 54° 22'; which, reduced to time, is 3 hours 37½ min. that is, IX h. 37½ min. in the forenoon, or II h. 22½ min. in the afternoon.

Put the altitude = 18°, whose natural fine is .3090170; and thence A - LD will be = .0491953; which divided by l + d, gives .0717179, the fine of  $4^{\circ}$   $6^{\prime}\frac{1}{2}$ , in time  $16^{\prime}\frac{1}{4}$  minutes nearly, before VI in the morning or after VI in the evening, when the fun's altitude is 18°.

And, if the declination 20° had been toward the fouth pole, the fun would have been depressed 18° below the horizon at 16½ minutes after VI in the evening; at which time, the twilight would end; which happens about the 22d of November, and 19th of January, in the latitude of 51°½ north. The same way may the end of twilight, or beginning of dawn, be found for any time of the year.

NOTE 1. If in theorem 2 and 3 (page 363) A is put = 0, and the value of H is computed, we have the hour of fun-rifing and fetting for any latitude, and time of the year. And if we put H=0, and compute A, we have the fun's altitude or depression at the hour of VI. And lastly, if H, A, and D are given, the latitude may be found by the resolution of a quadratic equation; for  $l=\sqrt{1-L^2}$ .

NOTE 2. When A is equal 0, H is equal  $\frac{LD}{ld} = TL \times TD$ , the tangent of the latitude

multiplied by the tangent of the declination.

As, if it was required, what is the greatest length of day in latitude 51° 30'?

To the log. tangent of 51° 30' 0.0993948

Add the log. tangent of 23° 29' 1.6379563

Their fum - 1.7373511 is the log. fine of the hour-diffance  $33^{\circ}$  7'; in time 2 h.  $12\frac{1}{2}$  m. The longest day therefore is 12 h. + 4 h. 25 m. = 16 h. 25 m. And the shortest day is 12 h. - 4 h. 25 m. = 7 h. 35 m.

And if the longest day is given, the latitude of the place is found;  $\frac{H}{TD}$  being equal to TL.

Thus, if the longest day is  $13\frac{1}{2}$  hours = 2 × 6 h. + 45 m. and 45 minutes in time being equal to  $11\frac{1}{4}$  degrees.

From the log. fine of 11° 15′ 1.2902357 Take the log. tang. of 23° 29′ 1.6379562

Remains - - 1.6522795 = the logarithmic tangent of lat. 24° 11'.

And the same way, the latitudes, where the several geographical climates and parallels begin, may be found; and the latitudes of places, that are assigned in authors from the length of their days, may be examined and corrected.

NOTE 3. The same rule for finding the longest day in a given latitude, distinguishes the hour-lines that are necessary to be drawn on any dial from those which would be superstuous.

In lat. 52° 10' the longest day is 16 h. 32 m. and the hour-lines are to be marked from 44 m.

after

after III in the morning, to 16 m. after VIII

in the evening.

In the same latitude, let the dial of Art. 7. Fig. 4. be proposed; and the elevation of its stile (or the latitude of the place d, whose horizon is parallel to the plane of the dial) being 15° 9'; the longest day at d, that is, the longest time that the fun can illuminate the plane of the dial, will (by the rule  $H = TL \times TD$ ) be twice 6 hours 27 minutes = 12 h. 54 m. The difference of longitude of the planes d and Z was found in the fame example to be 36° 21; in time, 2 hours 24 minutes; and the declination of the plane was from the fouth toward the west. Adding therefore 2 h. 24 min. to 5 h. 33 m. the earliest fun-rising on a horizontal dial at d, the fum 7 h. 57 m. shews that the morning hours, or the parallel dial at Z, ought to begin at 3 min. before VIII. And to the latest fun-fetting at d, which is 6 h. 27 m. adding the fame 2 h. 24 m. the fum 8 h. 51 m. exceeding 6 h. 16 m. the latest sun-setting at Z, by 35 m. shews that none of the afternoon hour-lines are superfluous. And the 4 h. 13 m. from III h. 44 m. the fun-rising at Z to VII h. 57 m. the fun-rising at d, belong to the other face of the dial; that is, to a dial declining 36° from north to east, and inclining 15°.

#### EXAMPLE III.

From the fame data to find the fun's azimuth.

If H, L, and D are given, then (by Art. 2. of Rule II.) from H, having found the altitude and its complement Zd; and the arc PD (the distance

distance from the pole) being given; say, As the co-sine of the altitude is to the sine of the distance from the pole, so is the sine of the hour-distance from the meridian to the sine of the azimuth distance from the meridian.

Let the latitude be 51° 30' north, the declination 15° 9' fouth, and the time II h. 24 m. in the afternoon, when the fun begins to illuminate a vertical wall, and it is required to find the

position of the wall.

Then, by the foregoing theorems, the complement of the altitude will be  $81^{\circ}$   $32^{\prime}\frac{1}{2}$ , and Pd the distance from the pole being  $109^{\circ}$  5', and the horary distance from the meridian, or the angle dPZ,  $36^{\circ}$ .

To log. fine 74° 51' - 1.98464 Add log. fine 36° 0' - 1.76922

And from the fum - 1.75386

Take the log. fine 81°  $32^{l\frac{1}{2}}$  1.99525

Remains - - 1.75861 = log.

fine 35°, the azimuth distance fouth.

When the altitude is given, find from thence

the hour, and proceed as above.

This praxis is of fingular use on many occasions: in finding the declination of vertical planes more exactly than in the common way, especially if the transit of the sun's center is observed by applying a ruler with fights, either plane or telescopical, to the wall or plane, whose declination is required.—In drawing a meridianline, and finding the magnetic variation.—In finding the bearings of places in terrestrial surveys; the transits of the sun over any place, or his horizontal distance from it being observed, together with the altitude and hour.—And thence

thence determining small differences of longitude.—In observing the variation at sea, &c.

The learned Mr. Andrew Reid invented an instrument several years ago, for finding the latitude at sea from two altitudes of the sun, observed on the same day, and the interval of the observations, measured by a common watch. And this instrument, whose only fault was that of its being somewhat expensive, was made by Mr. Jackson. Tables have been lately computed for that purpose.

But we may often, from the foregoing rules, resolve the same problem without much trouble; especially if we suppose the master of the ship to know within 2 or 3 degrees what his latitude is,

Thus,

Assume the two nearest probable limits of the latitude, and by the theorem  $H = \frac{A + LD}{ld}$ , com-

pute the hours of observation for both suppositions. If one interval of those computed hours coincides with the interval observed, the question is solved. If not, the two distances of the intervals computed, from the true interval, will give a proportional part to be added to, or subtracted from, one of the latitudes assumed. And if more exactness is required, the operation may be repeated with the latitude already found.

But whichever way the question is solved, a proper allowance is to be made for the difference of latitude arising from the ship's course in the

time between the two observations.

Of the double horizontal dial; and the Babylonian and Italian dials.

To the gnomonic projection, there is sometimes added a stereographic projection of the hour-circles, and the parallels of the sun's declination, on the same horizontal plane; the upright side of the gnomon being sloped into an edge, standing perpendicularly over the center of the projection: so that the dial, being in its due position, the shadow of that perpendicular edge is a vertical circle passing through the sun, in the stereographic projection.

The months being duly marked on the dial, the fun's declination, and the length of the day at any time, are had by infpection; as also his altitude, by means of a scale of tangents. But its chief property is, that it may be placed true, whenever the sun shines, without the help of

any other instrument.

Let d be the fun's place in the stereographic projection, x d y z the parallel of the sun's declination, Z d a vertical circle through the sun's center, P d the hour-circle; and it is evident, that the diameter NS of this projection being placed duly north and south, these three circles will pass through the point d. And therefore, to give the dial its due position, we have only to turn its gnomon toward the sun, on a horizontal plane, until the hour on the common gnomonic projection coincides with that marked by the hour-circle P d, which passes through the intersection of the shadow Z d with the circle of the sun's present declination.

The Babylonian and Italian dials reckon the hours, not from the meridian, as with us, but

Fig. 3.

from

from the fun's rising and setting. Thus, in Italy, Plate one hour before sun-set is reckoned the 23d hour, two hours before sun-set the 22d hour; and so of the rest. And the shadow that marks them on the hour-lines, is that of the point of a stile. This occasions a perpetual variation between their dials and clocks, which they must correct from time to time, before it arises to any sensible quantity, by setting their clocks so much faster or slower. And in Italy they begin their day, and regulate their clocks, not from sun-set, but from about mid-twilight, when the Ave Maria is said; which corrects the difference that would otherwise be between the clock and the dial.

The improvements which have been made in all forts of inftruments and machines for measuring time, have rendered such dials of little account. Yet, as the theory of them is ingenious, and they are really, in some respects, the best contrived of any for vulgar use, a general idea of their description may not be unacceptable.

Let Fig. 5. represent an erect direct south wall, on which a *Babylonian dial* is to be drawn, shewing the hours from sun-rising; the latitude of the place, whose horizon is parallel to the wall, being equal to the angle KCR. Make, as for a common dial KG = KR (which is perpendicular to CR) the radius of the equinoctial AEQ, and draw RS perpendicular to CK for the stile of the dial; the shadow of whose point R is to mark the hours, when SR is set upright on the plane of the dial.

Then it is evident, that in the contingent line  $\mathbb{Z} \ \mathcal{Q}$ , the spaces  $K_1, K_2, K_3, \&c$ . being taken equal to the tangents of the hour-distances from the meridian, to the radius KG, one, two, three, &c. hours after sun-rising, on the equinoctial day; the shadow of the point R will be R be found,

found, at these times, respectively in the points

1, 2, 3, &c.

Draw, for the like hours after fun-rifing, when the fun is in the tropic of Capricorn v, the like common lines CD, CE, CF, &c. and at these hours the shadow of the point R will be found in those lines respectively. Find the sun's altitudes above the plane of the dial at these hours, and with their co-tangents Sd, Se, Sf, &c. to radius SR, describe arcs intersecting the hour-lines in the points d, e, f, &c. so shall the right lines 1d, 2e, 3f, &c. be the lines of I, II, II, &c. hours after sun-rising.

The construction is the same in every other case, due regard being had to the difference of longitude of the place at which the dial would be horizontal, and the place for which it is to serve. And likewise, taking care to draw no lines but what are necessary; which may be done partly by the rules already given for determining the time that the sun shines on any plane; and partly from this, that on the tropical days, the hyperbola described by the shadow of the point R,

limits the extent of all the hour-lines.

The most useful however, as well as the simplest of such dials, is that which is described

on the two fides of a meridian plane.

That the Babylonian and Italic hours are truly enough marked by right lines, is easily shewn. Mark the three points on a globe, where the horizon cuts the equinoctial, and the two tropics, toward the east or west; and turn the globe on its axis 15°, or 1 hour; and it is plain, that the three points which were in a great circle (viz. the horizon) will be in a great circle still; which will be projected geometrically into a straight line. But these three points are universally the sun's

fun's places, one hour after fun-set (or one hour before sun-rise) on the equinoctial and solftitial days. The like is true of all other circles of declination, beside the tropics; and therefore, the hours on such dials are truly marked by straight lines limited by the projections of the tropics; and which are rightly drawn, as in the foregoing example.

Note 1. The same dials may be delineated without the hour-lines CD, CE, CF, &c. by setting off the sun's azimuths on the plane of the dial, from the center S, on either side of the substille CSK, and the corresponding co-tangents of altitude from the same center S, for I, II, III, &c. hours before or after the sun is in the horizon of the place for which the dial is to serve, on the equinoctial and solftitial days.

2. One of these dials has its name from the hours being reckoned from fun-rifing, the beginning of the Babylonian day. But we are not thence to imagine that the equal hours, which it shews, were those in which the astronomers of that country marked their observations. Thefe, we know with certainty, were unequal, like the Tewish, as being twelfth parts of the natural day: and a hour of the night was, in like manner, a twelfth part of the night; longer or shorter, according to the feafon of the year. So that a hour of the day, and a hour of the night, at the fame place, would always make 1 of 24, or 2 equinoctial hours. In Palestine, among the Romans, and in several other countries, 3 of these unequal nocturnal hours were a vigilia or watch. And the reduction of equal and unequal hours into one another, is extremely easy. If, for instance, it is found, by a foregoing rule, that in a certain latitude, at a given time of the year, the B b 2 length

length of a day is 14 equinoctial hours, the unequal hour is then \(\frac{14}{12}\) or \(\frac{7}{6}\) of a hour, that is, 70 minutes; and the nocturnal hour is 50 minutes. The first watch begins at VII (fun-set); the second at three times 50 minutes after; viz. IX h. 30 m. the third always at midnight; the

morning watch at 1 hour past II.

If it were required to draw a dial for shewing these unequal hours, or 12th parts of the day, we must take as many declinations of the sun as are thought necessary, from the equator toward each tropic: and having computed the sun's altitude and azimuth for  $\frac{1}{12}$ ,  $\frac{2}{12}$ ,  $\frac{3}{12}$ th parts, &c. of each of the diurnal arcs belonging to the declinations assumed: by these, the several points in the circles of declination, where the shadow of the stile's point falls, are determined: and curve lines drawn through the points of a homologous division will be the hour-lines required.

Of the right placing of dials, and having a true meridian line for the regulating of clocks and watches.

The plane on which the dial is to rest, being duly prepared, and every thing necessary for fixing it, you may find the hour tolerably exact by a large equinoctial ring-dial, and set your watch to it. And then the dial may be fixed by

the watch at your leifure.

If you would be more exact, take the fun's altitude by a good quadrant, noting the precise time of observation by a clock or watch. Then, compute the time for the altitude observed (by the rule, page 364) and set the watch to agree with that time, according to the sun. A Hadley's quadrant

quadrant is very convenient for this purpose; for by it you may take the angle between the sun and his image, reslected from a bason of water: the half of which angle, subtracting the refraction, is the altitude required. This is best done in summer, and the nearer the sun is to the prime vertical (the east or west azimuth) when the observation is made, so much the better.

Or, in summer, take two equal altitudes of the sun in the same day; one any time between 7 and 10 in the morning, the other between 2 and 5 in the afternoon; noting the moments of these two observations by a clock or watch: and if the watch shews the observations to be at equal distances from noon, it agrees exactly with the sun; if not, the watch must be corrected by half the difference of the forenoon and afternoon intervals; and then the dial may be set true by the watch.

Thus, for example, fuppose you have taken the sun's altitude when it was 20 minutes past VIII in the morning by the watch; and found, by observing in the afternoon, that the sun had the same altitude 10 minutes before IV; then it is plain, that the watch was 5 minutes too fast for the sun: for 5 minutes after XII is the middle time between VIII h. 20 m. in the morning, and III h. 50 m. in the afternoon; and therefore, to make the watch agree with the sun, it must be set back sive minutes.

A good meridian line, for regulating clocks A merior watches, may be had by the following me-dian line. thod.

Make a round hole, almost a quarter of an inch diameter, in a thin plate of metal; and six the plate in the top of a fouth window, in such a B b 3 manner,

manner, that it may recline from the zenith at an angle equal to the co-latitude of your place, as nearly as you can guess; for then, the plate will face the sun directly at noon on the equinoctial days. Let the sun shine freely through the hole into the room; and hang a plumb-line to the ceiling of the room; at least five or six feet from the window, in such a place as that the sun's rays, transmitted through the hole, may fall upon the line when it is noon by the clock; and having marked the said place on the ceiling, take away the line.

Having adjusted a sliding bar to a dove-tail groove, in a piece of wood about 18 inches long, and fixed a hook into the middle of the bar, nail the wood to the above-mentioned place on the ceiling, parallel to the fide of the room in which the window is: the groove and bar being toward the floor. Then, hang the plumb-line upon the hook in the bar, the weight or plummet reaching almost to the floor; and the whole

will be prepared for farther and proper adjust-

ment.

This done, find the true folar time by either of the two last methods, and thereby regulate your clock. Then, at the moment of next noon by the clock, when the fun shines, move the fliding bar in the groove until the shadow of the plumb-line bifects the image of the fun (made by his rays transmitted through the hole) on the floor, wall, or on a white screen placed on the north fide of the line; the plummet or weight at the end of the line hanging freely in a pail of water placed below it on the floor,-But because this may not be quite correct for the first time, on account that the plummet will not fettle immediately, even in water; it may be farther corrected rected on the following days, by the above method, with the fun and clock; and so brought to

a very great exactness.

N. B. The rays transmitted through the hole, will cast but a faint image of the sun, even on a white screen, unless the room be so darkened that no sun-shine may be allowed to enter, but what comes through the small hole in the plate. And always, for some time before the observation is made, the plummet ought to be immersed in a jar of water, where it may hang freely; by which means the line will soon become steady, which otherwise would be apt to continue swinging.

As this meridian line will not only be sufficient for regulating of clocks and watches to the true time by equation tables, but also for most astronomical purposes, I shall say nothing of the magnificent and expensive meridian lines at Bologne and Rome, nor of the better methods by which astronomers observe precisely the transits of the heavenly bodies on the meridian.

#### LECT. XII.

Shewing how to calculate the mean time of any New or Full Moon, or Eclipse, from the creation of the world to the year of Christ 5800.

In the following tables, the mean lunation is about a 20th part of a fecond of time longer than its measure as now printed in the last edition of my astronomy; which makes the difference of a hour and 30 minutes in 8000 years.—But this is not material, when only the mean times are required.

Bb4 PRE-

#### PRECEPTS.

To find the mean time of any New or Full Moon in any given year and month after the Christian Æra.

- column of the Table of the moon's mean motion from the fun, under the title, Years before and after CHRIST; write out that year, with the mean motions belonging to it, and thereto join the given month with its mean motions. But, if the given year be not in the table, take out the next lesser one to it that you find, in the same column; and thereto add as many complete years, as will make up the given year: then, join the given month, and all the respective mean motions.
- 2. Collect these mean motions into one sum of figns, degrees, minutes, and seconds; remembering that 60 seconds (") make a minute, 60 minutes (') a degree; 30 degrees (°) a sign, and 12 signs (°) a circle. When the signs exceed 12, or 24, or 36 (which are whole circles) reject them, and set down only the remainder; which, together with the odd degrees, minutes and seconds already set down, must be reckoned the whole sum of the collection.
- 3. Subtract the refult, or fum of this collection, from 12 figns; and write down the remainder. Then, look in the table, under Days, for the next less mean motions to this remainder, and

and fubtract them from it, writing down their remainder.

This done, look in the table under hours (marked H.) for the next less mean motions to this last remainder, and subtract them from it, writing down their remainder.

Then, look in the table under minutes (marked M.) for the next less mean motions to this remainder, and subtract them from it, writing down their remainder.

Lastly, look in the table under feconds (marked S.) for the next less mean motions to this remainder, either greater or less; and against it you have the seconds answering thereto,

4. And these times collected, will give the mean time of the required new moon; which will be right in common years; and also in January and February in leap years; but always one day too late in leap years after February.

#### EXAMPLE I.

Required the time of new moon in September, 1764?
(a year not inferted in the table)

	Moor	fro	om f	in.
To the year after Christ's		0		"
birth - 1753	10	9	24	16
Add compleat years 11		10		-
(fum 1764)				
And join September -	2	22	21	8
The fum of these mean motions is Which, being sub. from a circle,		12	0	24
or		0	0	0
Leaves remaining - Next less mean mot. for 26 days,		17	59	36
fub		16	57	34
And there remains  Next less mean mot. for 2 hours,	•	1	2	2
fub		I	0	57
And the remainder will be - Next less mean mot. for 2 min.			I	5
fub			1	I
Remains the mean mot. of 12 fec.				4

These times, being collected, would shew the mean time of the required new moon in September 1764, to be on the 26th day, at 2 hours 2 min. 12 sec. past noon. But, as it is in a leapyear, and after February, the time is one day too late. So, the true mean time is September the 25th, at 2 m. 12 sec. past II in the afternoon.

N. B.

N. B. The tables always begin the day at noon, and reckon thenceforward, to the noon of the day following.

To find the mean time of full moon in any given year and month after the Christian Æra.

Having collected the moon's mean motion from the fun for the beginning of the given year and month, and subtracted their sum from 12 signs (as in the former example) add 6 signs to the remainder, and then proceed in all respects as above.

#### EXAMPLE II.

Required the mean time of full moon in September 1764?

To the year after Christ's	Mo	on	fro	m f	un.
birth - 1753 Add complete years 11	1			24 14	
(fum 1764) And join September	-	2	22	21	8
The fum of these mean me is Which, being subtracted fr	-	1	12	0	24
circle, or -		2	0	0	0
Leaves remaining To which remainder add	-			59	
And the fum will be		4	17	59	36
			В	rou	ght

	Moon			un.
Brought over - Next less mean mot, for 11		17	59	36
days, fubt	4	14	5	54
And there remains  Next less mean mot, for 7		3	53	42
hours, fubt	-	3	<b>3</b> 3	20
And the remainder will be Next less mean mot. for 40	•		20	22
minutes, fubt.	-		20	19
Remains the mean mot. for 8				
feconds – –				3

So, the mean time, according to the tables, is the 11th of September, at 7 hours 40 minutes 8 feconds past noon. One day too late, being after February in a leap-year.

And thus may the mean time of any new or full moon be found, in any year after the Christian

Æra.

To find the mean time of new or full moon in any given year and month before the Christian Æra.

If the given year before the year of CHRIST I be found in the third column of the table, under the title Years before and after CHRIST, write it out, together with the given month, and join the mean motions. But, if the given year be not in the table, take out the next greater one to it that you find; which being still farther back than the given year, add as many compleat years to it as will bring the time forward to the given year; then join the month, and proceed in all respects as above.

EXAM-

#### EXAMPLE III.

Required the mean time of new moon in May, the year before Christ 585?

The next greater year in the table is 600; which being 15 years before the given year, add the mean motions for 15 years to those of 600, together with those for the beginning of May.

Ŋ	Moo	n fr	om	fun.
To the year before <i>Christ</i> 600 Add compleat years motion 15 And the mean motions for May	6	0	55	16 24 23
The whole fum is Which, being fubt. from a circle,	0	4	55	3
or	12	0	0	0
Leaves remaining - Next less mean mot. for 29 days,	11	25	4	57
fubt	II	23	3.1	54
And there remains  Next lefs mean mot. for 3 hours		I	33	3
fubt		1	31	26
And the remainder will be - Next less mean mot. for 3 min.			1	37
fubt			I	31
Rem. the mean mot. of 14 fe-				6
			9	So.

So, the mean time by the tables, was the 29th of May, at 3 hours 3 min. 14 fec. past noon. A day later than the truth, on account of its being in a leap-year. For as the year of CHRIST 1 was the first after a leap-year, the year 585 before the year 1 was a leap-year of course.

If the given year be after the Christian Æra, divide its date by 4, and if nothing remains, it is a leap-year in the old style. But if the given year was before the Christian Æra (or Year of CHRIST 1) subtract one from its date, and divide the remainder by 4; then, if nothing remains, it was a leap-year; otherwise not.

To find whether the sun is eclipsed at the time of any given change, or the moon at any given full.

Ofeclipses. From the Table of the sun's mean motion (or distance) from the moon's ascending node, collect the mean motions answering to the given time; and if the result shews the sun to be within 18 degrees of either of the nodes at the time of new moon, the sun will be eclipsed at that time. Or, if the result shews the sun to be within 12 degrees of either of the nodes at the time of sull moon, the moon will be eclipsed at that time, in or near the contrary node; otherwise not.

#### EXAMPLE IV.

The moon changed on the 26th of September 1764, at 2 b. 2 m. (neglecting the seconds) after noon. (See Example 1.) Qu. Whether the sun was eclipsed at that time?

To t	he year after Christ's	St		fron	n no	de.
	th - 1753		1	28	0	19
	compleat years 11		7	28 2	3	56
And	(fum 1764) September - 26 days - 2 hours - 2 minutes -		8	1 2 27	0	
	2 minutes -	-				5
Sun's	distance from the ascend	ding	6	9	32	34

Now, as the descending node is just opposite to the ascending (viz. 6 signs distant from it) and the tables shew only how far the sun has gone from the ascending node, which, by this example, appears to be 6 signs 9 degrees 32 minutes 34 seconds, it is plain that he must have then been eclipsed; as he was then only 9° 32′ 34″ short of the descending node.

#### EXAMPLE V.

The moon was full on the 11th of September, 1764, at 7 h. 40 min. post noon. (See Example II.) Qu. Whether she was eclipsed at that time?

To the year after Christ's	Sun from node.
birth - 1753	1 28 0 19
Add compleat years 11	1 28 0 19 7 2 3 56
And {September	8 12 22 49 11 25 29 - 18 11 - 1 44
Sun's distance from the ascer	nd- 5 24 12 28

Which being subtracted from 6 signs, leaves only 5° 47′ 32″ remaining; and this being all the space that the sun was short of the descending node, it is plain that the moon must then have been eclipsed, because she was just as near the contrary node.

#### EXAMPLE VI.

2. Whether the sun was eclipsed in May, the year before CHRIST 585? (See Example III.)

	Sun	fron		
To the year before Christ 600 - Add the mean motion of 15	9	9	23	51
complete years  May  29 days 3 hours 3 minutes (neglecting the feconds)	4 1	19 4 0	37 7	57
Sun's distance from the ascending node		3	44	43

Which being less than 18 degrees, shews that

the fun was eclipsed at that time.

This eclipse was foretold by Thales, and is Thales's thought to be the eclipse which put an end to the eclipse. war between the Medes and Lydians.

The times of the fun's conjunction with the When nodes, and consequently the eclipse months of any eclipses given year, are easily found by the Table of the must hapfun's mean motion from the moon's ascending node; and much in the same way as the mean conjunctions of the sun and moon are found by the table of the moon's mean motion from the sun. For, collect the sun's mean motion from the node (which is the same as his distance gone from it) for the beginning of any given year, and subtract it from 12 signs; then, from the

remainder, subtract the next less mean motions belonging to whatever month you find them in the table; and from their remainder subtract the next less mean motion for days, and so on for hours and minutes; the result of all which will shew the time of the sun's mean conjunction with the ascending node of the moon's orbit.

#### EXAMPLE VII.

Required the time of the sun's conjunction with the ascending node in the year 1764?

To the year after Christ's	Sun	fron		
birth — 1753 Add compleat years — 11	I	28	0	19
Mean dist. at beg. of A. D. 1764 Subtract this distance from a	9	0	4	15
circle, or	12	0	0	0
And there remains —— Next less mean motion for	2	29	55	45
March, subtract	2	I	16	39
And the remainder will be Next less mean motion for 27		28	39	6
days, subtract -		28	2	32
And there remains  Next less mean motion for 14			36	34
hours, fubtracted	_		36	21
Remains (nearly) the mean mo- tion of 5 minutes				13
			He	nce

Hence it appears, that the sun will pass by the moon's ascending node on the 27th of March, at 14 hours 5 minutes past noon; viz. on the 28th day, at 5 minutes past II in the morning, according to the tables: but this being in a leap-year, and after February, the time is one day too late. Consequently, the true time is at 5 min. past II in the morning on the 27th day; at which time, the descending node will be directly opposite to the sun.

If 6 figns be added to the remainder arising from the first subtraction (viz. from 12 figns) and then the work carried on as in the last example, the result will give the mean time of the sun's conjunction with the descending node. Thus, in

#### EXAMPLE VIII.

To find when the fun will be in conjunction with the descending node in the year 1764?

To the year after Christ's  birth — i753  Add compleat years 11		fron 28 2	0	19
M. d. fr. afc. n. at beg. of 1764 Subtract this diftance from a circle, or	9	0	4 0	
And the remainder will be — To which add half a circle, or	- 2	29	55	45
And the fum will be	8	29	55	45
Cc2		Ė	Brou	ght

	Su	in fi	. no	ode.
		0	1	11
Brought over — Next less mean mot. for Sept. subt.		29 12		
And there remains  Next less mean mot. for 16 days,		17	32	56
fubt.	_	16	37	4
And the remainder will be Next less mean mot. for 21 hours,			55	52
fubtracted ——	_		54	32
Rem. (nearly) the mean mot. of 31 minutes			I	20

So that, according to the tables, the sun will be in conjunction with the descending node on the 16th of September, at 21 hours 31 minutes past noon: one day later than the truth, on account of the leap-year.

The limits of eclipses.

When the moon changes within 1'8 days before or after the sun's conjunction with either of the nodes, the sun will be eclipsed at that change: and when the moon is sull within 12 days before or after the time of the sun's conjunction with either of the nodes, she will be eclipsed at that sull: otherwise not.

Their period and restitu-

If to the mean time of any eclipse, either of the sun or moon, we add 557 Julian years 21 days 18 hours 11 minutes and 51 seconds (in which there are exactly 6890 mean lunations) we shall have the mean time of another eclipse. For at the end of that time, the moon will be either new or sull, according as we add it to the time of new or sull moon; and the sun will be only 45" farther from the same node, at the end of the

the faid time, than he was at the beginning of it; as appears by the following example \*.

Sun fr. node. The period. Moon fr. fun. 32 47-10 14 45 5 500-Compleat 40-8 25 50 37- 1 23 58 49 Years ( 2 21 39-10 28 40 15 21-8 16 0 21- 21 48 38 days 9 8 35hours 46 44 minutes 5 35-29 feconds 26-51-Mean motions —o

And this period is so very near, that in 6000 years it will vary no more from the truth, as to the restitution of eclipses, than 8½ minutes of a degree; which may be reckoned next to nothing. It is the shortest in which, after many trials, I can find so near a conjunction of the sun, moon, and the same node.

\* Dr. Halley's period of eclipses contains only 18 years 11 days 7 hours 43 minutes 20 seconds; in which time, according to his tables, there are just 223 mean lunations: but, as in that time, the sun's mean motion from the node is no more than 115 290 31' 49", which wants 28' 11" of being as nearly in conjunction with the same node at the end of the period, as it was at the beginning; this period cannot be of constant duration for finding eclipses, because it will in time fall quite without their limits. The following tables make this period 31 seconds shorter, as appears by the following calculation.

	C	c 3					This
Mean motions	0	0	0	0—11	29	31	49
fec.	44—			22—			2
minutes	42-		21	20-		1	49
hours				20-		18	11
days	11-4	14	5	54-	11	25	29
Compleat years				4-11			
The period.		oon	ir.	fun. Su	o o	. nc	ide.
ic following calcula			0				1-

This table is made by the continual addition of a mean lunation, viz. 29<sup>d</sup> 12<sup>h</sup> 44<sup>m</sup> 3<sup>s</sup> 6<sup>th</sup> 21<sup>ty</sup> 14<sup>v</sup> 24<sup>tl</sup> 0<sup>vll</sup>.

Lun.	Days.	Н.	M.	S.	Th	In 100000 mean lunations, there are 8085 Ju-
1	29	12	44	3		lian years 12 days 21 hours
2	59	I	28	6		36 minutes 30 feconds =
3	0 88	14	12	9	19	2953059 days 3 hours 36
4	9 118	2	56	12	25	minutes 30 feconds.
5	E. 147	15	40	15	32	Proof of the Table.
5	1 77	4	24	18	38	[Moon from fun.
7	205	17	8	21	44	In 8 0 ' "
7 8	236	5	52	24	51	E (4000 1 14 22 12
9	265	18	36	27	57	
10	295	7	20	31	3	80 5 23 41 15 5 10 0 18 28
20	590	14	41	2	7	
30	885	22	1	33	11	Days 12 4 26 17 20
40	1181	5	22	4	14	Hours 21 10 40 1
50	1476	12	42	35	18	Min. 36 18 17
100	2953	1	25	10	35	Sec. 20 15
200	5906	2	50	21	11	
300	8859	4	15	31	46	M. fr. fun. 0 0 0 0
400	11812	5	49	42	22	Having by the former
500	14756	7	5	52	57	precepts computed the
1000	29530	1+	11	45	54	mean time of new moon in
2000	59061	4	23	34	48	January, for any given
3000	88591	18	35	17	42	year, it is easy, by this Ta-
4000	118122	8	47	3		ble, to find the mean time
5000	147652	23	58	49		of new moon in January for
10000	295305	21	57	39	0	any number of years after-
	590611	19	55	18	Ó	ward: and by means of a
	885917	17	52	57		finall table of lunations for
	1476529	15	50	36	0	12 or 13 months, to make
100000	2953059	13	48 36	15	0	a general table for finding
,00000	933039	3	30	39		the mean time of new or
						full moon in any given year
						and month whatever.
						D. H. M. S. Th.
Intr	Iunations	the	re a	re	3	24 20 4 34 10.
The second second	lunations			-	3	54 8 48 37 16.
	lunations		-	-	3	83 21 32 40 23.
But then	it would	be	best	to	beg	gin the year with March,
		ven	ienc	e of	lo	fing a day by mistake in
eap-year						

Years	Years	Vez	rs before	1 <sub>M</sub>	ion f	rom	fun	Com-	IM.	000	from	fun.
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Seriod	world.	CH	R4SI.	1 "				years.	1.			
		_		-					-			
706	0		4008	5	28	1	17	11	0	10	14	20
714	8	1	4000	5.	9	23	24	12	5	2	3	11
1714	1008	-	3000	11	20	28	57	13	9	11		
2714	2008	-	2000	6	I	34	30	14	1	21		
	3008	CHRIST	1000	0	12	40			6			100
3714	3000	Z Z		10			3	15	1	2 4 5 7	23	
3814	3108	C	900		19	46	36	16	10		1.6	
3914	3208	4	800	8	26	53	9	17	3	2		39
4014	3308	0	700	7	3	59	43	18	17	II		4
4114	3408	e a	600	5	11	6	16	19	11	21	36	27
4214	3508	>	500	3.	18	12	49	20	14	13		19
+314	3608	Before the Year of	400	1	25	19	23	40	18	26		37
4414	3708	7	300	0	2	25	56	60	1	10		56
	3/00	ore		10	9	32		80				
4514	3808	ef	200	8	16		29	- 1000	5	23	41	15
4614	3908	100	100			39	3,	100	10	7	6	33
4714	4008	-After	I	6	23	+5	36	200	8	14	13	7
4814	4108	A	101	5	0	52	9	300	6	21	19	40
4914	4208	6	201	3	7	58	43	400	4	28	26	13
5014	4308	C	301	1	15	5	16	500	3	5	32	47
5114	4408	0		11	22	11	49	1000	6	11	5	33
52:4	4508	HRIST.	1	9	29	18	23	2000	0	22	11	6
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2 3	2.9	36	366	6			17	Sept.	2	22	21	8
2:0	ea d	20	998 7			22	7	Oct.	2	28	4	29
18 H	500	ulian years, 3 of have 365 days,	4 9				32	Nov.	3	15		17
100	de le	3-5		8				Dec.				
CHRIST I, was the 4007th	55-	_	. 10.			36	5511				42	_7
The 4008th year before the year of CHRIST I, was the 4007th year	is supposed to have been the of the creation.	This	table a	gre	es u	rith	the	old Stile	unti	1 th	e ye	ar
=			1753;	an	d af	ter	that	, with t	he ?	recu		
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1 1 2 2 2 3 3 4 4 4 4	6 18 0 13 25 7 19 1	34 45 57 8 20 31 43 54	20 47 13 40 7 34 0	3 4 5 6	I I 2 2	31 1	57 26	32	16	15 45	16
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2 3 3 4 4 4	13 25 7 19 1	8 20 31 43 54	40 7 34 0	5 6	2 2	I			100		
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		5	54	9	4	34	18	39	19	48	36
	26	17	20	10	5	4	46	40	20	19	
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		1-1-1	11			39					22
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	17		47	29	14	43	50	59	29	58	8
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34 27 13 0 16 57 34 27 13 0 17 54 47 29 14 0 17 54 47 29 14 0 17 54 47 29 14	5 20 40 14 12 6 5 6 2 51 40 13 6 36 6 15 3 7 14 7 6 6 27 14 34 15 7 37 7 9 26 0 16 8 7 7 21 37 27 17 8 38 8 3 48 54 18 9 8 8 16 0 21 19 9 39 8 28 11 47 20 10 9 9 10 23 14 21 10 40 9 22 34 41 22 11 10 9 4 46 7 23 11 40 9 22 34 41 22 11 10 9 4 46 7 23 11 40 9 10 27 26 13 12 11 20 27 26 13 12 12 3 31 54 27 13 42 10 5 43 21 28 14 13 10 17 54 47 29 14 43 10 6 15 30 15 14	5 20 40 14 12 6 5 43 6 2 51 40 13 6 36 12 6 15 3 7 14 7 6 41 6 27 14 34 15 7 37 9 16 27 14 34 15 7 37 9 8 38 6 8 3 48 54 18 9 8 35 8 16 0 21 19 9 39 4 8 28 11 47 20 10 9 32 10 23 14 21 10 40 1 22 34 44 22 11 10 30 14 46 7 23 11 40 58 11 20 27 26 13 12 24 12 3 31 54 27 13 42 53 15 43 21 26 17 54 47 29 14 43 50 17 54 47 29 14 43 50 17 54 47 29 14 43 50 17 54 47 29 14 43 50 17 54 47 29 14 43 50 17 54 47 29 14 43 50 17 54 47 29 14 43 50 17 54 47 29 14 43 50 17 54 47 29 14 43 50 17 54 47 29 14 43 50 17 54 47 29 14 43 50 17 54 47 29 14 43 50 17 54 47 29 14 43 50 17 54 47 29 14 43 50 17 54 47 29 14 43 50 15 14 18	5       20       40       14       12       6       5       43       42         6       2       51       40       13       6       36       12       43         6       15       3       7       14       7       6       41       44         6       27       14       34       15       7       37       9       45         7       9       26       0       16       8       7       38       46         7       21       37       27       17       8       38       6       47         8       3       48       54       18       9       8       35       48         8       16       0       21       19       9       39       4       49         8       28       11       47       20       10       9       32       50         9       10       23       14       21       10       40       1       51         9       22       34       41       22       11       10       30       52         9       1       25       12	5       20       40       14       12       6       5       43       42       21         6       2       51       40       13       6       36       12       43       21         6       15       3       7       14       7       6       41       44       22         6       27       14       34       15       7       37       9       45       22         7       9       26       0       16       8       7       38       46       23         8       3       48       54       18       9       8       35       48       24         8       16       0       21       19       9       39       4       49       24         8       28       11       47       20       10       9       32       50       25         9       10       23       14       21       10       40       1       51       25         9       12       31       40       58       53       26       26         9       14       46       7       23       11 <td>5       20       40       14       12       6       5       43       42       21       20         6       2       51       40       13       6       36       12       43       21       50         6       15       3       7       14       7       6       41       44       22       20         6       27       14       34       15       7       37       9       45       22       51         7       9       26       0       16       8       7       38       46       23       21         7       21       37       27       17       8       38       6       47       23       52         8       3       48       54       18       9       8       35       48       24       22         8       16       0       21       19       9       39       4       49       24       53         8       28       11       47       20       10       9       32       50       25       23         9       12       31       10       40       1</td>	5       20       40       14       12       6       5       43       42       21       20         6       2       51       40       13       6       36       12       43       21       50         6       15       3       7       14       7       6       41       44       22       20         6       27       14       34       15       7       37       9       45       22       51         7       9       26       0       16       8       7       38       46       23       21         7       21       37       27       17       8       38       6       47       23       52         8       3       48       54       18       9       8       35       48       24       22         8       16       0       21       19       9       39       4       49       24       53         8       28       11       47       20       10       9       32       50       25       23         9       12       31       10       40       1

In leap years, after February, a day and its motion must be added to the time for which the moon's mean distance from the sun is given. But, when the mean time of any new or full moon is required in leap-year after February, a day must be subtracted from the mean time thereof, as found by the tables. In common years they give the day right.

Years of the	Years	Year	s before	Sui	n fro	m no	ode.	Com-	Su	n fr	om r	ode
Julian	of the World.		after RIST.	s	0		"	pleat years.	5	0		
period	world.		K151.					years.		Ů		
706	0		4008		6	17	9	11	17	2	3	56
714	8		4000		11	4	55	12	17	22	11	39
1714	1008	-	3000	9	10	35	11	13	8	II	17	2
2714	2008	ST	2000	1	10	5	28	14	9	0	22	25
3714	3008	CHRIST	1000		9	35	44	15	9	19	27	49
3814	3108	E	900		24	32	46	16	10	9	35	31
3914	3208		800	1	9	29	48	17	10	28	40	55
4014	3308	Before the Year of	700		24	26	49	18	II	17	46	18
4114	3408	ea	600		9	23	51	19	0	6	51	43
4214	3508	>	500	1	24	20	53	20	0	26	59	24
4314	3608	至	400		9	17	54	40	1	23	58	49
4414	3708	15	300	10	24	14	56	60	2	20	58	13
4514	3808	g	200	3	9	11	58	80	3	17	57	37
4614	3908		100	7	24	8	59	100	4	14	57	. 2
4714	4008		I	0	9	6	1	200	8	29	54	3
4814	4108	Af	101	4	24	3	3	300	I	14	51	5
4914	4208	-After	201	9	9	0	4	400	5	29	48	5 7 8
5014	4308	0	301	1	23	57	6	500	10	14	45	
5114	4408	HRIST	401	6	8	54	8	1000	8	29	30	17
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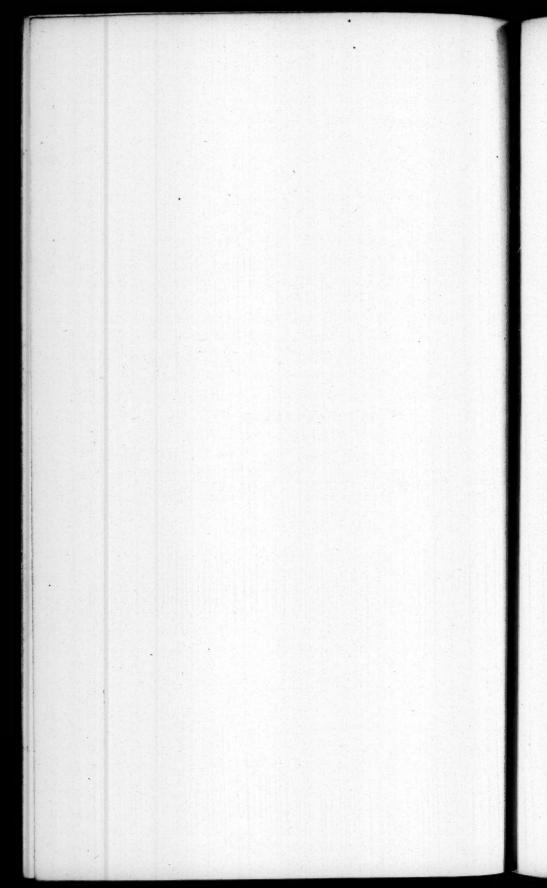
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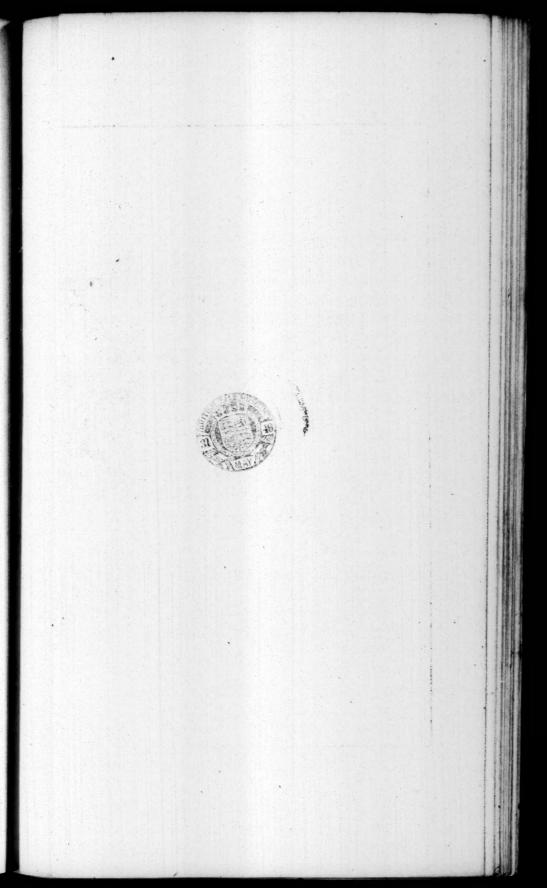
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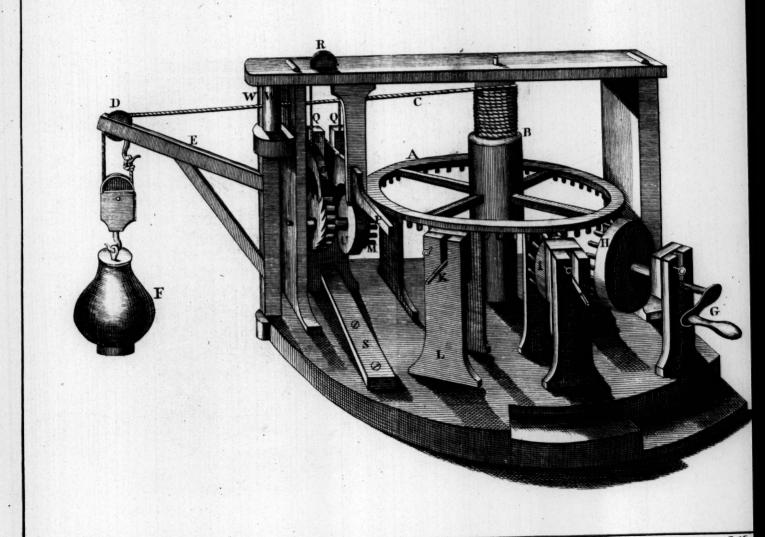
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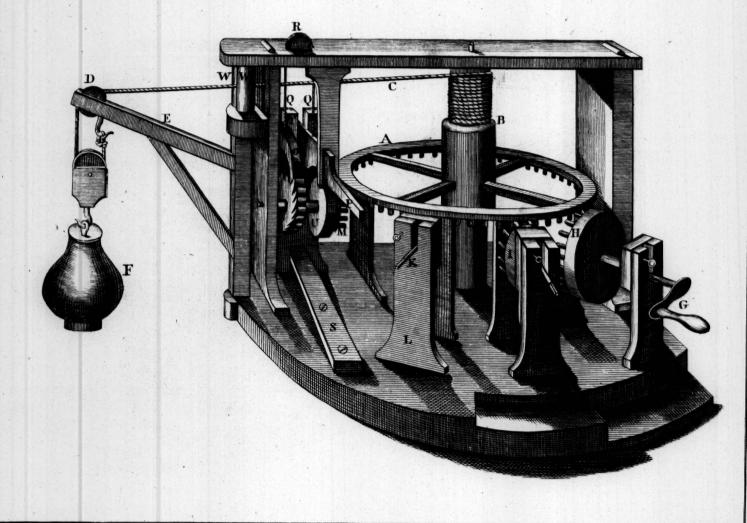






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### SUPPLEMENT

TO THE PRECEDING

## LECTURES.

#### MECHANICS.

The Description of a new and safe Crane, which has sour different Powers, adapted to different Weights.

HE common crane consists only of a large wheel and axle; and the rope, by which goods are drawn up from ships, or let down from the quay to them, winds or coils round by the axle, as the axle is turned by men walking in the wheel. But, as these engines have nothing to stop the weight from running down, if any of the men happen to trip or fall in the wheel, the weight descends, and turns the wheel rapidly backward, and tosses the men violently about within it; which has produced melancholy instances, not only of limbs D d 2

#### MECHANICS.

broke, but even of lives lost, by this ill-judged construction of cranes. And besides, they have but one power for all sorts of weights; so that they generally spend as much time in raising a small weight, as in raising a great one.

These impersections and dangers induced me to think of a method of remedying them. And for that purpose, I contrived a crane with a proper stop to prevent the danger, and with different powers suited to different weights; so that there might be as little loss of time as possible: and also, that when heavy goods are let down into ships, the descent may be regular and deliberate.

This crane has four different powers: and, I believe, it might be built in a room eight feet in width: the gib being on the outside of the room.

Three trundles, with different numbers of staves, are applied to the cogs of a horizontal wheel with an upright axle; and the rope, that draws up the weight, coils round the axle. wheel has 96 cogs, the largest trundle 24 staves, the next largest has 12, and the smallest has 6. So that the largest trundle makes 4 revolutions for one revolution of the wheel; the next makes 8, and the smallest makes 16. A winch is occasionally put upon the axis of either of these. trundles, for turning it; the trundle being then used that gives a power best suited to the weight: and the handle of the winch describes a circle in every revolution equal to twice the circumference of the axle of the wheel. So that the length

length of the winch doubles the power gained by each trundle.

As the power gained by any machine, or engine whatever, is in direct proportion as the velocity of the power is to the velocity of the weight; the powers of this crane are eafily eftimated, and they are as follows.

If the winch be put upon the axle of the largest trundle, and turned four times round, the wheel and axle will be turned once round: and the circle described by the power that turns the winch, being, in each revolution, double the circumference of the axle, when the thickness of the rope is added thereto; the power goes through eight times as much space as the weight rifes through: and therefore (making fome allowance for friction) a man will raise eight times as much weight by the crane as he would by his natural strength without it: the power, in this case, being as eight to one.

If the winch be put upon the axis of the next trundle, the power will be as fixteen to one, because it moves 16 times as fast as the weight moves.

If the winch be put upon the axis of the fmallest trundle, and turned round; the power will be as 32 to one.

But if the weight should be too great, even for this power to raife, the power may be doubled by drawing up the weight by one of the parts of a double rope, going under a pulley in the moveable block, which is hooked to the weight below the arm of the gib; and then the Dd 3

power will be as 64 to one. That is, a man could then raise 64 times as much weight by the crane as he could raise by his natural strength without it; because, for every inch that the weight rises, the working power will move through 64 inches.

By hanging a block with two pullies to the arm of the gib, and having two pullies in the moveable block that rifes with the weight, the rope being doubled over and under these pullies, the power of the crane will be as 128 to one. And so, by increasing the number of pullies, the power may be increased as much as you please: always remembering, that the larger the pullies are, the less is their friction.

While the weight is drawing up, the ratchteeth of a wheel slip round below a catch or click that falls successively into them, and so hinders the crane from turning backward, and detains the weight in any part of its ascent, if the man who works at the winch should accidentally happen to quit his hold, or choose to rest himself before the weight be quite drawn up.

In order to let down the weight, a man pulls down one end of a lever of the second kinds which lifts the catch of the ratchet-wheel, and gives the weight liberty to descend. But, if the descent be too quick, he pulls the lever a little farther down, so as to make it rub against the outer edge of a round wheel; by which means he lets down the weight as slowly as he pleases: and, by pulling a little harder, he may stop the weight, if needful, in any part of its descent.

2

r

If he accidentally quits hold of the lever, the catch immediately falls, and stops both the weight and the whole machine.

This crane is represented in PLATE I. where A is the great wheel, and B its axle on which the rope C winds. This rope goes over a pulley D in the end of the arm of the gib E, and draws up the weight F, as the winch G is turned round. H is the largest trundle, I the next, and K is the axis of the smallest trundle, which is supposed to be hid from view by the upright supporter L. A trundle M is turned by the great wheel, and on the axis of this trundle is fixed the ratchet-wheel N, into the teeth of which the catch O falls. P is the lever. from which goes a rope QQ, over a pulley R to the catch; one end of the rope being fixed to the lever, and the other end to the catch. is an elastic bar of wood, one end of which is fcrewed to the floor: and, from the other end goes a rope (out of fight in the figure) to the further end of the lever, beyond the pin or axis on which it turns in the upright supporter T. The use of this bar is to keep up the lever from rubbing against the edge of the wheel U, and to let the catch keep in the teeth of the ratchetwheel: but a weight hung to the farther end of the lever would do full as well as the elaftic bar and rope.

When the lever is pulled down, it lifts the catch out of the ratchet-wheel, by means of the rope  $\mathcal{Q}\mathcal{Q}$ , and gives the weight F liberty to descend: but if the lever P be pulled a little farther down than what is sufficient to lift the catch O out of the ratchet-wheel N, it will rub D d 4 against

#### MECHANICS.

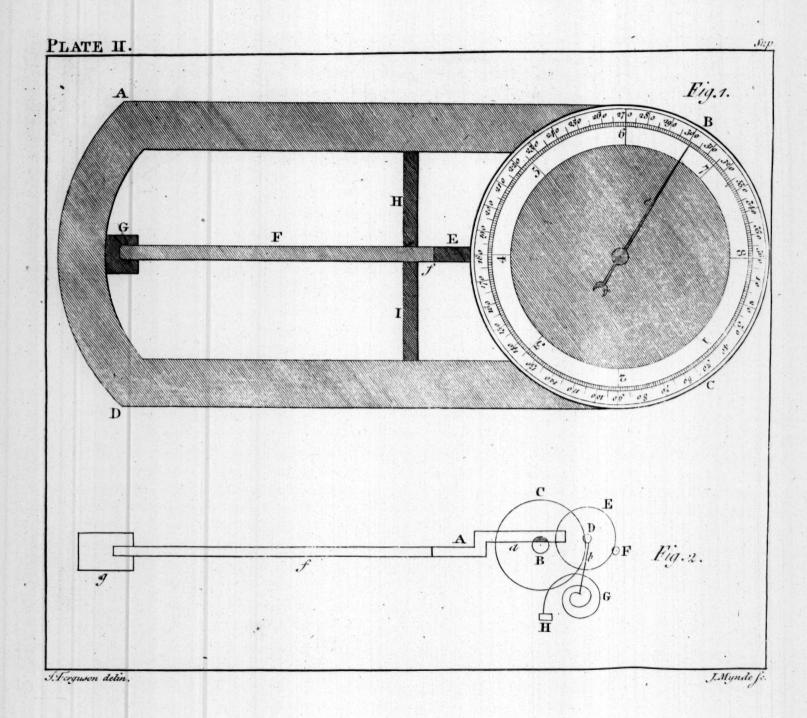
against the edge of the wheel *U*, and thereby hinder the too quick descent of the weight; and will quite stop the weight if pulled hard. And if the man who pulls the lever, should happen inadvertently to let it go; the elastic bar will suddenly pull it up, and the catch will fall down and stop the machine.

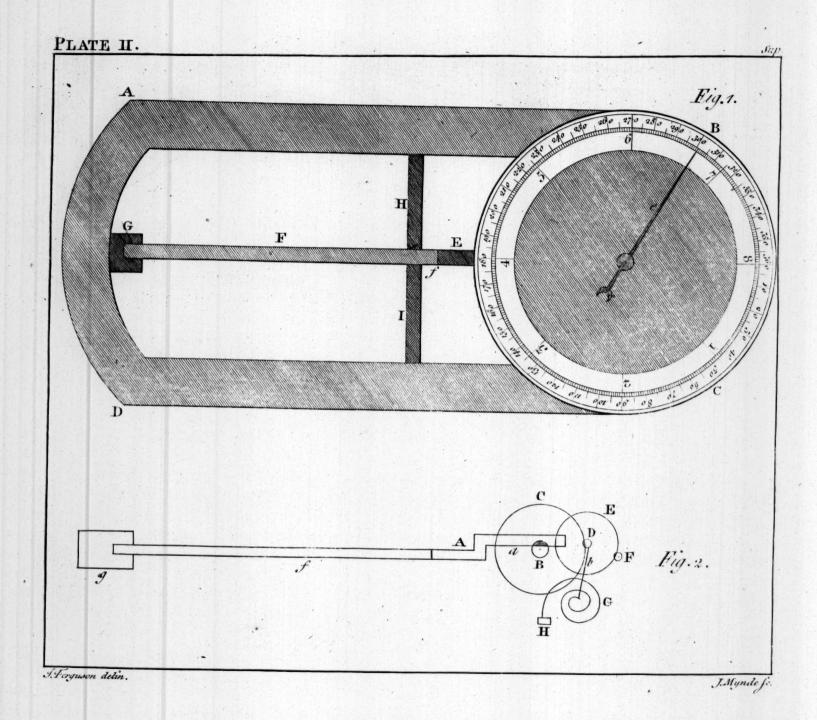
WW are two upright rollers above the axis or upper gudgeon of the gib E: their use is to let the rope C bend upon them, as the gib is turned to either side, in order to bring the weight over the place where it is intended to be let down.

N. B. The rollers ought to be so placed, that if the rope C be stretched close by their utmost sides, the half thickness of the rope may be perpendicularly over the center of the upper gudgeon of the gib. For then, and in no other position of the rollers, the length of the rope between the pulley in the gib and the axle of the great wheel will be always the same, in all positions of the gib: and the gib will remain in any position to which it is turned.

When either of the trundles is not turned by the winch in working the crane, it may be drawn off from the wheel, after the pin near the axis of the trundle is drawn out, and the thick piece of wood is raised a little behind the outward supporter of the axis of the trundle. But this is not material: for, as the trundle has no friction on its axis but what is occasioned by its weight, it will be turned by the wheel without any sensible resistance in working the crane.







A Pyrometer, that makes the Expansion of Metals by Heat visible to the five and forty thousandth Part of an Inch.

The upper furface of this machine is reprefented by Fig. 1. of Plate II. Its frame ABCD is made of mahogany wood, on which is a circle divided into 360 equal parts; and within that circle is another, divided into 8 equal parts. the short bar E be pushed one inch forward (or toward the center of the circle) the index e will be turned 125 times round the circle of 360 parts or degrees. As 125 times 360 is 45,000, 'tis evident, that if the bar E be moved only the 45,000dth part of an inch, the index will move one degree of the circle. But as in my pyrometer, the circle is 9 inches in diameter, the motion of the index is visible to half a degree, which answers to the ninety thousandth part of an inch in the motion or pushing of the short bar E.

One end of a long bar of metal F is laid into a hollow place in a piece of iron G, which is fixed to the frame of the machine; and the other end of this bar is laid against the end of the short bar E, over the supporting cross bar HI: and, as the end f of the long bar is placed close against the end of the short bar, it is plain, that if F expands, it will push E forward, and turn the index e.

The machine stands on four short pillars, high enough from a table, to let a spirit-lamp be put on the table under the bar F; and when that is done, the heat of the slame of the lamp expands the bar, and turns the index.

There

There are bars of different metals, as filver, brass, and iron; all of the same length as the bar F, for trying experiments on the different expansions of different metals, by equal degrees of heat applied to them for equal lengths of time; which may be measured by a pendulum, that swings seconds. Thus,

Put on the brass bar F, and set the index to the 360th degree: then put the lighted lamp under the bar, and count the number of seconds in which the index goes round the plate, from 360 to 360 again; and then blow out the lamp, and take away the bar.

This done, put on an iron bar F where the brass one was before, and then set the index to the 360th degree again. Light the lamp, and put it under the iron bar, and let it remain just as many seconds as it did under the brass one; and then blow it out, and you will see how many degrees the index has moved in the circle: and by that means you will know in what proportion the expansion of iron is to the expansion of brass; which I find to be as 210 is to 360, or as 7 is to 12.—By this method, the relative expansions of different-metals may be found.

The bars ought to be exactly of equal fize; and to have them fo, they should be drawn, like wire, through a hole.

When the lamp is blown out, you will fee the index turn backward; which shews that the metal contracts as it cools.

The infide of this pyrometer is constructed as follows.

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In Fig. 2. Aa is the short bar which moves between rollers; and, on the side a it has 15 teeth in an inch, which take into the leaves of a pinion B (12 in number) on whose axis is the wheel C of 100 teeth, which take into the 10 leaves of the pinion D, on whose axis is the wheel E of 100 teeth, which take into the 10 leaves of the pinion F, on the top of whose axis is the index above-mentioned.

Now, as the wheels C and E have 100 teeth each, and the pinions D and F have ten leaves each; it is plain, that if the wheel C turns once round, the pinion F and the index on its axis will turn 100 times round. But, as the first pinion E has only 12 leaves, and the bar Ae that turns it has 15 teeth in an inch, which is 12 and a fourth part more; one inch motion of the bar will cause the last pinion E to turn a hundred times round, and a fourth part of a hundred over and above, which is 25. So that, if E be pushed one inch, E will be turned 125 times round.

A filk thread b is tied to the axis of the pinion D, and wound feveral times round it; and the other end of the thread is tied to a piece of slender watch-spring G which is fixed into the stud H. So that, as the bar f expands, and pushes the bar Aa forward, the thread winds round the axle, and draws out the spring; and as the bar contracts, the spring pulls back the thread, and turns the work the contrary way, which pushes back the short bar Aa against the long bar f. This spring always keeps the teeth of the wheels in contact with the leaves of

the pinions, and so prevents any shake in the teeth.

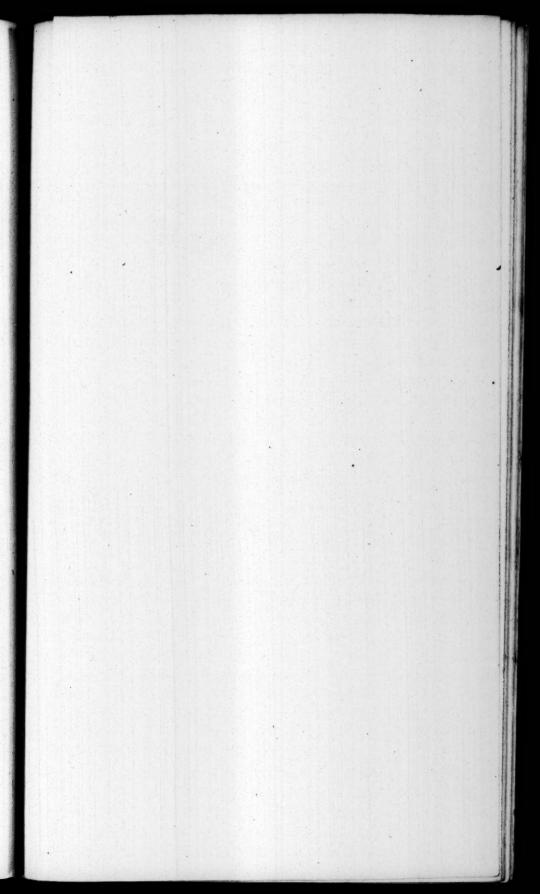
In Fig. 1. the eight divisions of the inner circle are so many thousandth parts of an inch in the expansion or contraction of the bars; which is just one thousandth part of an inch for each division moved over by the index.

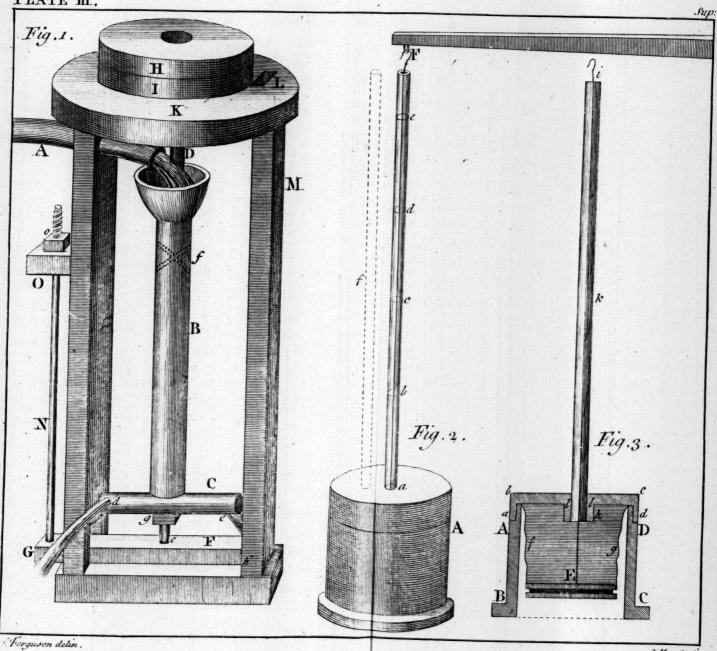
A Water-Mill, invented by Dr. Barker, that has neither Wheel nor Trundle.

This machine is represented by Fig. 1. of Plate III. in which, A is a pipe or channel that brings water to the upright tube B. The water runs down the tube, and thence into the horizontal trunk C, and runs out through holes at d and e near the ends of the trunk on the contrary sides thereof.

The upright spindle D is fixt in the bottom of the trunk, and screwed to it below by the nut g; and is fixt into the trunk by two cross bars at f: so that, if the tube B and trunk C be turned round, the spindle D will be turned also.

The top of the spindle goes square into the rynd of the upper mill-stone H, as in common mills; and, as the trunk, tube, and spindle turn round, the mill-stone is turned round thereby. The lower, or quiescent mill-stone is represented by I; and K is the floor on which it rests, and wherein is the hole L for letting the meal





J.Mynde fe.

meal run through, and fall down into a trough which may be about M. The hoop or case that goes round the mill-stone rests on the floor K, and supports the hopper, in the common way. The lower end of the spindle turns in a hole in the bridge-tree GF, which supports the mill-stone, tube, spindle, and trunk. This tree is moveable on a pin at b, and its other end is supported by an iron rod N sixt into it, the top of the rod going through the fixt bracket O, and having a screw-nut o upon it, above the bracket. By turning this nut forward or backward, the mill-stone is raised or lowered at pleasure.

While the tube B is kept full of water from the pipe A, and the water continues to run out from the ends of the trunk; the upper mill-flone H, together with the trunk, tube, and spindle turns round. But, if the holes in the trunk were stopt, no motion would ensue; even though the tube and trunk were full of water. For,

If there were no hole in the trunk, the preffure of the water would be equal against all parts of its sides within. But, when the water has free egress through the holes, its pressure there is entirely removed: and the pressure against the parts of the sides which are opposite to the holes, turns the machine.

#### HYDROSTATICS.

A Machine for demonstrating that, on equal Bottoms, the Pressure of Fluids is in Proportion to their perpendicular Heights, without any regard to their Quantities.

and the machine for shewing it is represented in Fig. 2. of Plate III. In which A is a box that holds about a pound of water, a b c de a glass-tube fixt in the top of the box, having a small wire within it; one end of the wire being hooked to the end F of the beam of a balance, and the other end of the wire fixt to a moveable bottom, on which the water lies, within the box; the bottom and wire being of equal weight with an empty scale (out of sight in the sigure) hanging at the other end of the balance. If this scale be pulled down, the bottom will be drawn up within the box, and that motion will cause the water to rise in the glass-tube.

Put one pound weight into the scale, which will move the bottom a little, and cause the water to appear just in the lower end of the tube at a; which shews that the water presses with the force of one pound on the bottom: put another pound into the scale, and the water will rise from a to b in the tube, just twice as high above the bottom as it was when at a; and then, as its pressure on the bottom supports two pound weight in the scale, it is plain that the pressure on the bottom is then equal to two pounds. Put a third pound weight in the scale, and the water

water will be raised from b to c in the tube. three times as high above the bottom as when it began to appear in the tube at a; which shews, that the same quantity of water that pressed, but with the force of one pound on the bottom, when raised no higher than a, presses with the force of three pounds on the bottom when raised three times as high to c in the tube. Put a fourth pound weight into the scale, and it will cause the water to rise in the tube from c to d, four times as high as when it was all contained in the box, which shews that its pressure then upon the bottom is four times as great as when it lay all within the box. Put a fifth pound weight into the scale, and the water will rise in the tube from d to e, five times as high as it was above the bottom before it rose in the tube; which shews that its pressure on the bottom is then equal to five pounds, feeing that it supports fo much weight in the scale. And so on, if the tube was still longer; for it would still require an additional pound put into the scale, to raise the water in the tube to an additional height equal to the space de; even if the bore of the tube was so fmall as only to let the wire move freely within it, and leave room for any water to get round the wire.

Hence we infer, that if a long narrow pipe or tube was fixed in the top of a cask sull of liquor, and if as much liquor was poured into the tube as would fill it, even though it were so small as not to hold an ounce weight of liquor; the pressure arising from the liquor in the tube would be as great upon the bottom,

and be in as much danger of bursting it out, as if the cask was continued up, in its full fize, to the height of the tube, and filled with liquor.

In order to account for this surprising affair, we must consider that sluids press equally in all manner of directions; and consequently that they press just as strongly upward as they do downward. For, if another tube, as f, be put into a hole made into the top of the box, and the box be filled with water; and then, if water be poured in at the top of the tube a b c d e, it will rise in the tube f to the same height as it does in the other tube: and if you leave off pouring, when the water is at c, or any other place in the tube a b c d e, you will find it just as high in the tube f: and if you pour in water to fill the first tube, the second will be filled also.

Now it is evident that the water rifes in the tube f, from the downward pressure of the water in the tube a b c de, on the surface of the water, contiguous to the infide of the top of the box; and as it will ftand at equal heights in both tubes, the upward pressure in the tube f is equal to the downward preffure in the other tube. But, if the tube f were put in any other part of the top of the box, the rifing of the water in it would still be the same: or, if the top was full of holes, and a tube put into each of them, the water would rife as high in each tube as it was poured into the tube abcde; and then the moveable bottom would have the weight of the water in all the tubes to bear, befide the weight of all the water in the box.

And feeing that the water is pressed upward into each tube, it is evident that, if they be all taken away, excepting the tube abcde, and the holes in which they flood be flopt up; each part, thus ftopt, will be pressed as much upward as was equal to the weight of water in each tube. So that, the upward pressure against the infide of the top of the box, on every part equal in breadth to the width of the tube abcde, will be pressed upward with a force equal to the whole weight of water in the tube. And confequently, the whole upward pressure against the top of the box, arifing from the weight or downward pressure of the water in the tube will be equal to the weight of a column of water of the fame height with that in the tube, and of the fame thickness as the width of the infide of the box: and this upward preffure against the top will re-act downward against the bottom and be as great thereon, as would be equal to the weight of a column of water as thick as the moveable bottom is broad, and as high as the water stands in the tube. And thus, the paradox is folved.

The moveable bottom has no friction against the infide of the box, nor can any water get between it and the box. The method of making it so, is as follows:

In Fig. 3. ABCD represents a section of the box, and abcd is the lid or top thereof, which goes on tight, like the lid of a common paper snuff-box. E is the moveable bottom, with a groove around its edge, and it is put into a bladder fg, which is tied close around it in the E e

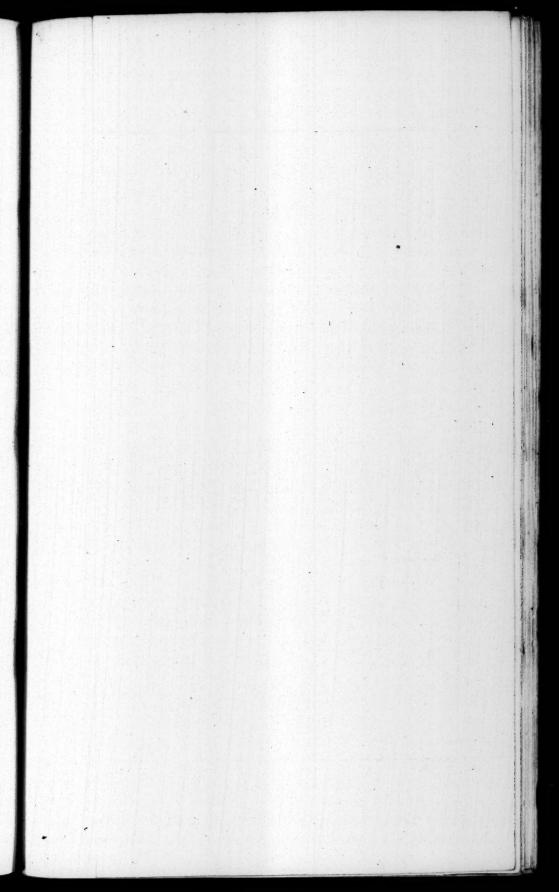
groove by a strong waxed thread; the bladder coming up like a purse within the box, and put over the top of it at a and d all round, and then the lid pressed on. So that, if water be poured in through the hole ll of the lid, it will lie upon the bottom E, and be contained in the space f E g b within the bladder; and the bottom may be raised by pulling the wire i, which is fixed to it at E: and by thus pulling the wire, the water will be listed up in the tube k, and as the bottom does not touch against the inside of the box, it moves without friction.

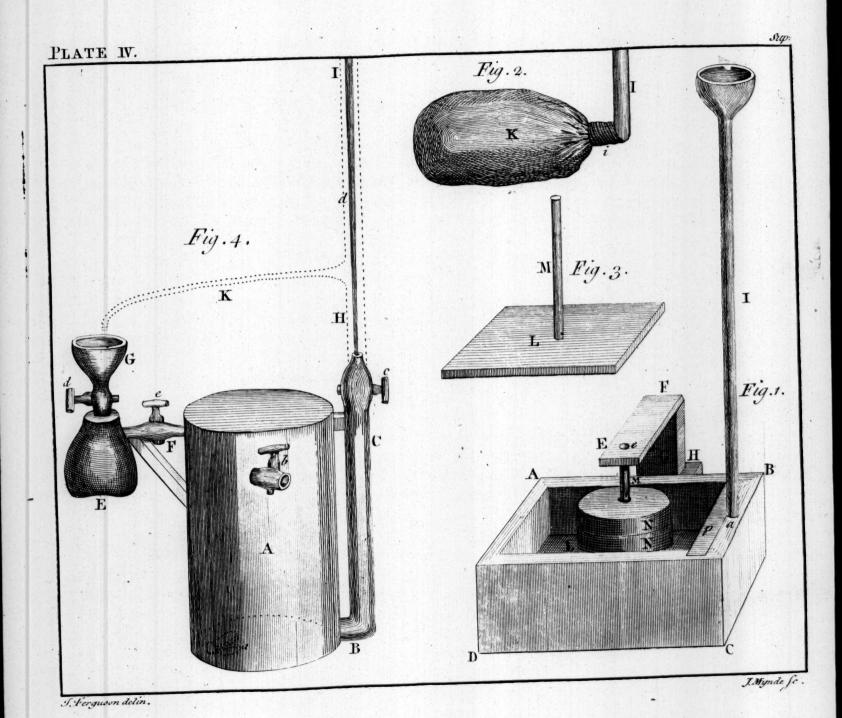
Now, suppose the diameter of this round bottom to be three inches (in which case, the area thereof will be 9 circular inches) and the diameter of the bore of the tube to be a quarter of an inch; the whole area of the bottom will be 144 times as great as the area of the top of a pin that would fill the tube like a cork.

And hence it is plain, that if the moveable bottom be raifed only the 14+th part of an inch, the water will thereby be raifed a whole inch in the tube; and confequently, that if the bottom be raifed one inch, it would raife the water to the top of a tube 144 inches, or 12 feet, in height.

N. B. The box must be open below the moveable bottom, to let in the air. Otherwise, the pressure of the atmosphere would be so great upon the moveable bottom, if it be three inches in diameter, as to require 108 pounds in the scale, to balance that pressure, before the bottom could begin to move.

A Machine,





A Machine, to be substituted in place of the common Hydrostatical Bellows.

In Fig. 1. of PLATE IV. ABCD is an oblong fiquare box, in one end of which is a round groove, as at a, from top to bottom, for receiving the upright glass tube 1, which is bent to a right angle at the lower end (as at i in Fig. 2.) and to that part is tied the neck of a large bladder K (Fig. 2.) which lies in the bottom of the box. Over this bladder is laid the moveable board L (Fig. 1 and 3.), in which is fixt an upright wire M; and leaden weights NN, to the amount of 16 pounds, with holes in their middle, which are put upon the wire, over the board, and press upon it with all their force.

The cross bar p is then put on, to secure the tube from falling, and keep it in an upright position: And then the piece EFG is to be put on, the part G sliding tight into the dove-tailed groove H, to keep the weights NN horizontal, and the wire M upright; there being a round hole e in the part EF for receiving the wire.

There are four upright pins in the four corners of the box within, each almost an inch long, for the board L to rest upon: to keep it from pressing the sides of the bladder below it close together at first.

The whole machine being thus put together, pour water into the tube at top; and the water will run down the tube into the bladder below the board; and after the bladder has been filled

up to the board, continue pouring water into the tube, and the upward preffure which it will excite in the bladder, will raise the board with all the weight upon it, even though the bore of the tube should be so small, that less than an ounce of water would fill it.

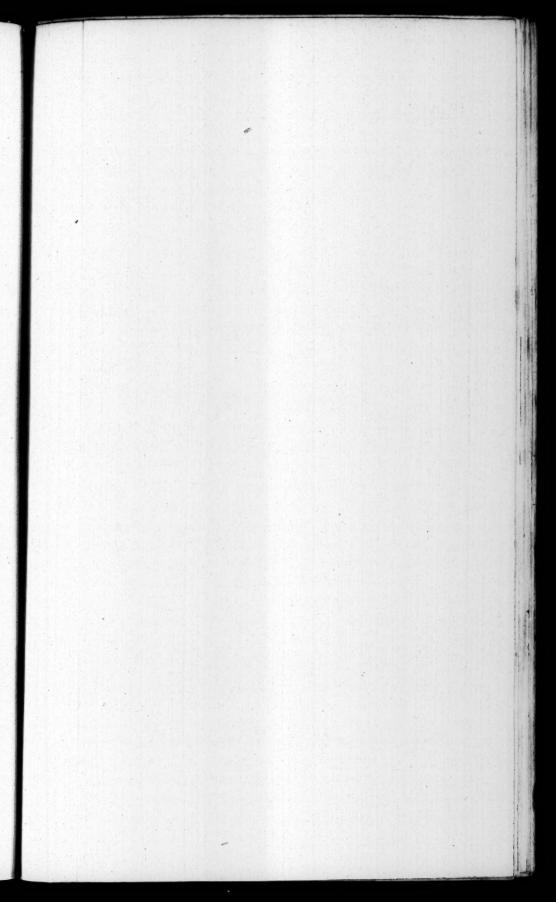
This machine acts upon the same principle, as the one last described, concerning the Hydro-statical paradox. For, the upward pressure against every part of the board (which the bladder touches) equal in area to the area of the bore of the tube, will be pressed upward with a force equal to the weight of the water in the tube; and the sum of all these pressures, against so many areas of the board, will be sufficient to raise it with all the weights upon it.

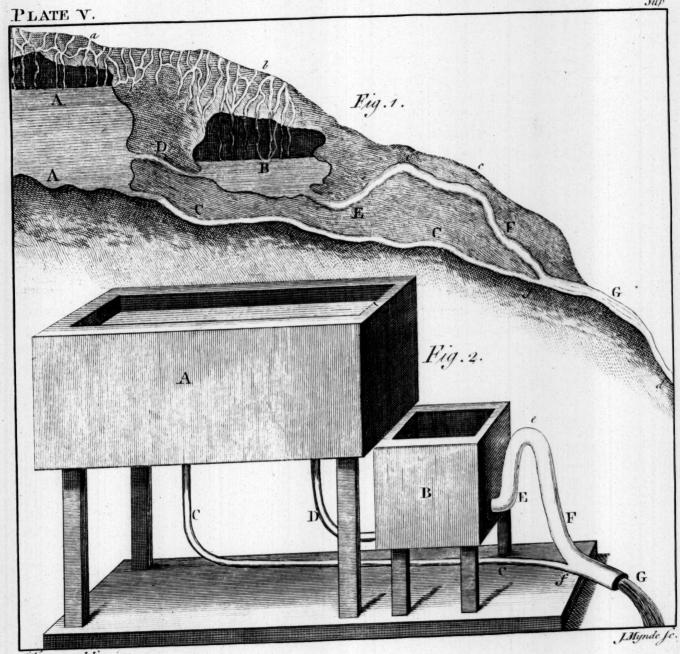
In my opinion, nothing can exceed this fimple machine, in making the upward preffure of fluids evident to fight.

The Cause of reciprocating Springs, and of ebbing and flowing Wells, explained.

In Fig. 1. of PLATE V. let abcd be a hill, within which is a large cavern AA near the top, filled or fed by rains and melted fnow on the top a, making their way through chinks and crannies into the faid cavern, from which proceeds a small stream CC within the body of the hill, and iffues out in a spring at G on the side of the hill, which will run constantly while the cavern is fed with water.

From the same cavern AA, let there be a small channel D, to carry water into the cavern





J. Ferguson delin .

B; and from that cavern let there be a bended channel EeF, larger than D, joining with the former channel CC, as at f before it comes to the fide of the hill: and let the joining at f be below the level of the bottom of both these caverns.

As the water rifes in the cavern B, it will rife as high in the channel E e F: and when it rifes to the top of that channel at e, it will run down the part e F G, and make a swell in the spring G, which will continue till all the water is drawn off from the cavern B, by the natural fyphon E e F (which carries off the water fafter from B than the channel D brings water to it) and then the fwell will ftop, and only the fmall channel CC will carry water to the fpring G, till the cavern B is filled to B again by the rill D; and then the water being at the top e of the channel EeF, that channel will act again as a fyphon, and carry off all the water from B to the spring G, and fo make a swelling flow of water at G as before.

To illustrate this by a machine (Fig. 2.) let A be a large wooden box, filled with water; and let a small pipe CC (the upper end of which is fixed into the bottom of the box) carry water from the box to G, where it will run off constantly, like a small spring. Let another small pipe D carry water from the same box to the box or well B, from which let a syphon EeF proceed, and join with the pipe CC at f: the bore of the syphon being larger than the bore of the seeding-pipe D. As the water from this pipe rises in the well B, it will also rise as high in the syphon EeF; and when the syphon is Ee 3

full to the top e, the water will run over the bend e, down the part eF, and go off at the mouth G; which will make a great stream at G: and that stream will continue, till the syphon has carried off all the water from the well B; the syphon carrying off the water faster from B than the pipe D brings water to it: and then the swell at G will cease, and only the water from the small pipe CC will run off at G, till the pipe D fills the well B again; and then the syphon will run, and make a swell at G as before.

And thus, we have an artificial representation of an ebbing and flowing well, and of a reciprocating spring, in a very natural and simple manner.

#### HYDRAULICS.

An Account of the Principles by which Mr. Blakey proposes to raise Water from Mines, or from Rivers, to supply Towns and Centlemen's Seats, by his new invented Fire-Engine, for which he has received His Majesty's Patent.

ALTHOUGH I am not at liberty to defcribe the whole of this simple engine, yet I have the patentee's leave to describe such a one as will shew the principles by which it acts.

In Fig. 4. of PLATE IV. let A be a large, ftrong, close vessel; immersed in water up to the cock b, and having a hole in the bottom, with a valve a upon it, opening upward within the vessel. A pipe B C rises from the bottom

of

of this vessel, and has a cock c in it near the top, which is small there, for playing a very high jet d. E is the little boiler (not so big as a common tea-kettle) which is connected with the vessel A by the steam pipe F; and G is a funnel, through which a little water must be occasionally poured into the boiler, to yield a proper quantity of steam. And a small quantity of water will do for that purpose, because steam possesses upward of 14,000 times as much space or bulk as the water does from which it proceeds.

The vessel A being immersed in water up to the cock b, open that cock, and the water will rush in through the bottom of the vessel at a, and fill it as high up as the water stands on its outside; and the water, coming into the vessel, will drive the air out of it (as high as the water rises within it) through the cock b. When the water has done rushing into the vessel, shut the cock b, and the valve a will fall down, and hinder the water from being pushed out that way, by any force that presses on its surface. All the part of the vessel above b, will be full of common air, when the water rises to b.

Shut the cock c, and open the cocks d and e; then pour as much water into the boiler E (through the funnel G) as will about half fill the boiler; and then that the cock d, and leave the cock e open.

This done, make a fire under the boiler E, and the heat thereof will raise a steam from the water in the boiler; and the steam will make its way thence, through the pipe F; into the E e A

vessel A; and the steam will compress the air (above b) with a very great force upon the surface of the water in A.

When the top of the veffel A feels very hot by the steam under it, open the coek c in the pipe C; and the air being strongly compressed in A, between the steam and the water therein, will drive all the water out of the vessel A, up the pipe B C, from which it will sly up in a jet to a very great height.—In my fountain, which is made in this manner after Mr. Blakey's, three tea-cup-sulls of water in the boiler will afford steam enough to play a jet 30 feet high.

When all the water is out of the vessel A, and the compressed air begins to sollow the jet, open the cocks b and d to let the steam out of the boiler E and vessel A, and shut the cock e to prevent any more steam from getting into A; and the air will rush into the vessel A through the cock b, and the water through the valve a; and so the vessel will be silled up with water to the cock b as before. Then shut the cock b and then, the next steam that rises in the boiler will make its way into the vessel A again; and the operation will go on, as above.

When all the water in the boiler E is evaporated, and gone off into steam, pour a little more into the boiler, through the funnel G.

In order to make this engine raise water to any gentleman's house; if the house be on the bank of a river, the pipe BC may be continued

up to the intended height, in the direction HI. Or, if the house be on the side or top of a hill, at a distance from the river, the pipe, through which the water is forced up, may be laid along on the hill, from the river or spring to the house.

The boiler may be fed by a small pipe K, from the water that rises in the main pipe BCHI; the pipe K being of a very small bore, so as to fill the sunnel G with water in the time that the boiler E will require a fresh supply. And then, by turning the cock d, the water will fall from the sunnel into the boiler. The sunnel should hold as much water as will about half fill the boiler.

When either of these methods of raising water, perpendicularly or obliquely, is used, there will be no occasion for having the cock c in the main pipe BCHI: for such a cock is requisite only, when the engine is used as a sountain.

A contrivance may be very easily made, from a lever to the cocks b, d, and e; so that, by pulling the lever, the cocks b and d may be opened when the cock e must be shut; and the cock e be opened when b and d must be shut.

The boiler E should be inclosed in a brick wall, at a little distance from it, all around; to give liberty for the slames of the fire under the boiler to ascend round about it. By which means (the wall not covering the sunnel G) the force of the steam will be prodigiously increased by the heat round the boiler; and the sunnel and water in it will be heated from the boiler; so that, the boiler

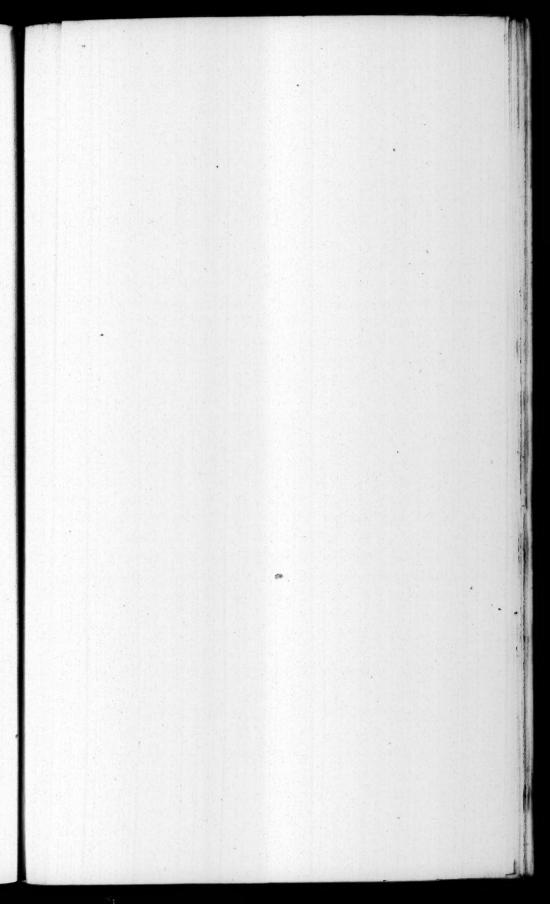
boiler will not be chilled by letting cold water into it; and the rifing of the fleam will be fo much the quicker.

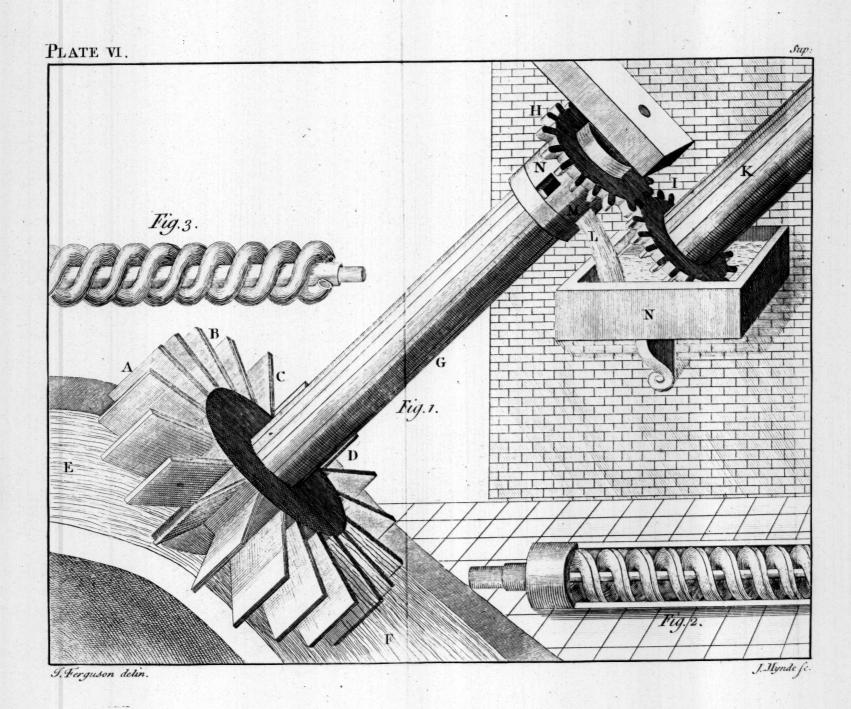
Mr. Blakey is the only person who ever thought of making use of air as an intermediate body between steam and water: by which means, the steam is always kept from touching the water, and consequently from being condensed by it. And, on this new principle, he has obtained a patent: so that no one (vary the engine how he will) can make use of air between steam and water, without infringing on the patent, and being subject to the penalties of the law.

This engine may be built for a trifling expence, in comparison of the common fire engine now in use: it will seldom need repairs, and will not consume half so much suel. And as it has no pumps with pistons, it is clear of all their friction: and the effect is equal to the whole strength or compressive force of the steam: which the effect of the common fire engine never is, on account of the great friction of the pistons in their pumps.

# ARCHIMEDES's Screw-Engine for raising Water.

In Fig. 1. of PLATE VI. ABCD is a wheel, which is turned round, according to the order of the letters, by the fall of water EF, which need not be more than three feet. The axle G of the wheel is elevated fo, as to make an angle of about 44 degrees with the horizon; and on the top of that axle is a wheel H, which turns fuch another wheel I of the fame number





of teeth: the axle K of this last wheel being parallel to the axle G of the two former wheels.

The axle G is cut into a double-threaded forew (as in Fig. 2.) exactly refembling the forew on the axis of the fly of a common jack, which must be (what is called) a right-handed forew, like the wood-forews, if the first wheel turns in the direction ABCD; but must be a left-handed forew, if the stream turns the wheel the contrary way. And, which-ever way the screw on the axle G be cut, the screw on the axle K must be cut the contrary way; because these axles turn in contrary directions.

The fcrews being thus cut, they must be covered close over with boards, like those of a cylindrical cask; and then they will be spiral tubes. Or, they may be made of tubes of stiff leather, and wrapt round the axles in shallow grooves cut therein; as in Fig. 3.

The lower end of the axle G turns constantly in the stream that turns the wheel, and the lower ends of the spiral tubes are open into the water. So that, as the wheel and axle are turned round, the water rises in the spiral tubes, and runs out at L, through the holes MN, as they come about below the axle. These holes (of which there may be any number, as four or six) are in a broad close ring on the top of the axle, into which ring, the water is delivered from the upper open ends of the screw-tubes, and falls into the open box N.

The lower end of the axle K turns on a gudgeon, in the water in N; and the fpiral tubes

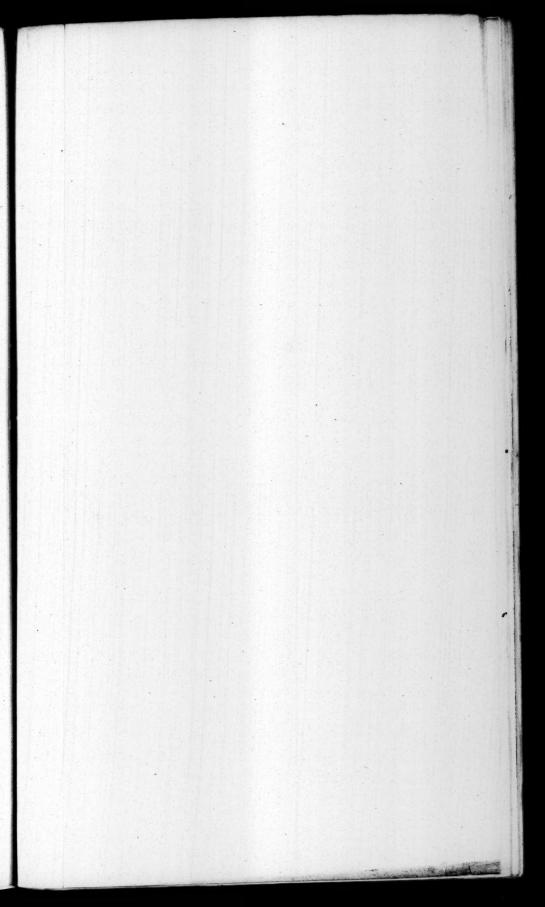
tubes in that axle take up the water from N, and deliver it into fuch another box under the top of K; on which there may be fuch another wheel as I, to turn a third axle by fuch a wheel upon it.—And in this manner, water may be raifed to any given height, when there is a ftream fufficient for that purpose to act on the broad float boards of the first wheel.

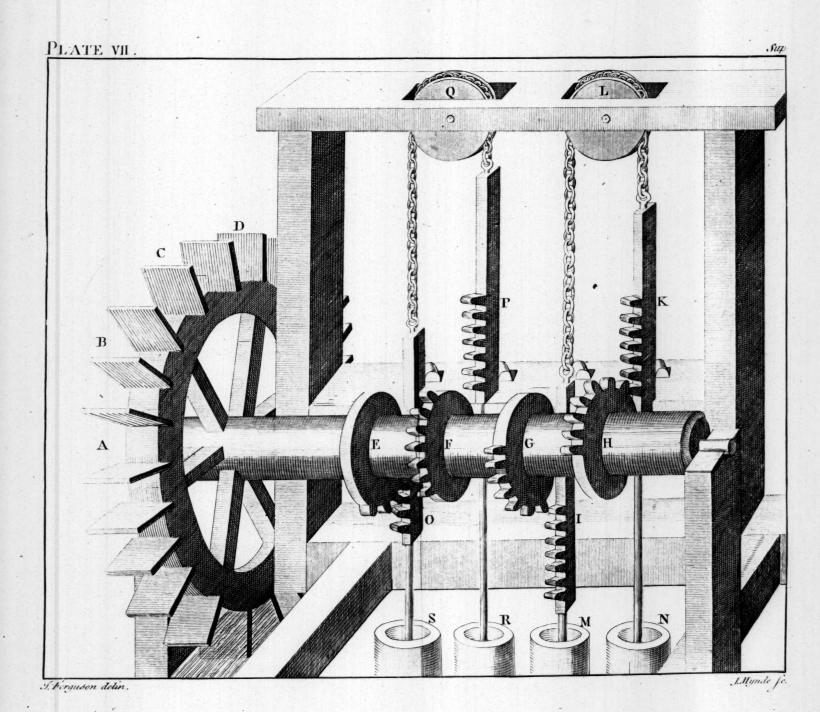
## A quadruple Pump-Mill for raising Water.

This engine is represented in PLATE VII. in which ABCD is a wheel, turned by water according to the order of the letters. On the horizontal axis are four small wheels, toothed almost half round: and the parts of their edges on which there are no teeth are cut down so, as to be even with the bottoms of the teeth where they stand.

The teeth of these four wheels take alternately into the teeth of four racks, which hang by two chains over the pullies  $\mathcal{Q}$  and L; and to the lower ends of these racks there are four iron rods fixed, which go down into the four forcing pumps,  $\mathcal{S}$ , R, M and N. And, as the wheels turn, the racks and pump-rods are alternately moved up and down.

Thus, suppose the wheel G has pulled down the rack I, and drawn up the rack K by the chain: as the last tooth of G just leaves the uppermost tooth of I, the first tooth of H is ready to take into the lowermost tooth of the rack K and pull it down as far as the teeth go;





and then the rack I is pulled upward through the whole space of its teeth, and the wheel G is ready to take hold of it, and pull it down again, and so draw up the other.—In the same manner, the wheels E and F work the racks O and P.

These four wheels are fixed on the axle of the great wheel in such a manner, with respect to the positions of their teeth; that, while they continue turning round, there is never one instant of time in which one or other of the pump-rods is not going down, and forcing the water. So that, in this engine, there is no occasion for having a general air-vessel to all the pumps, to procure a constant stream of water flowing from the upper end of the main pipe.

The piftons of these pumps are solid plungers, the same as described in the fifth Lecture of my book, to which this is a Supplement. See Plate XI. Fig. 4. of that book, with the description of the sigure.

From each of these pumps, near the lowest end, in the water, there goes off a pipe; with a valve on its farthest end from the pump; and these ends of the pipes all enter one close box, into which they deliver the water: and into this box, the lower end of the main conduct pipe is fixed. So that, as the water is forced or puthed into this box, it is also pushed up the main pipe to the height that it is intended to be raised.

There is an engine of this fort, described in Ramelli's work: but I can truly fay, that I never

never faw it till some time after I had made this model.

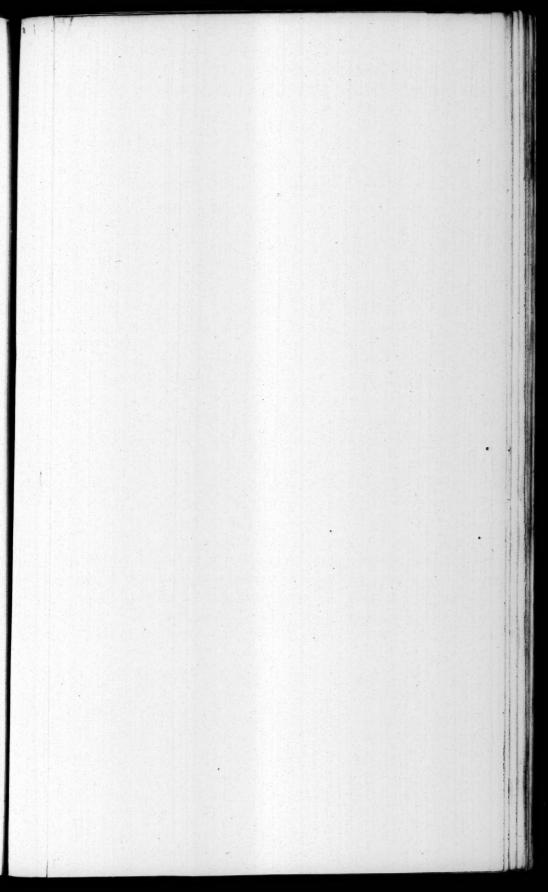
The faid model is not above twice as big as the figure of it, here described. I turn it by a winch fixed on the gudgeon of the axle behind the water wheel; and, when it was newly made, and the pistons had valves in good order, I put tin pipes 15 feet high upon it, when they were joined together, to see what it could do. And I found, that in turning it moderately by the winch, it would raise a hogshead of water in a hour, to the height of 15 feet.

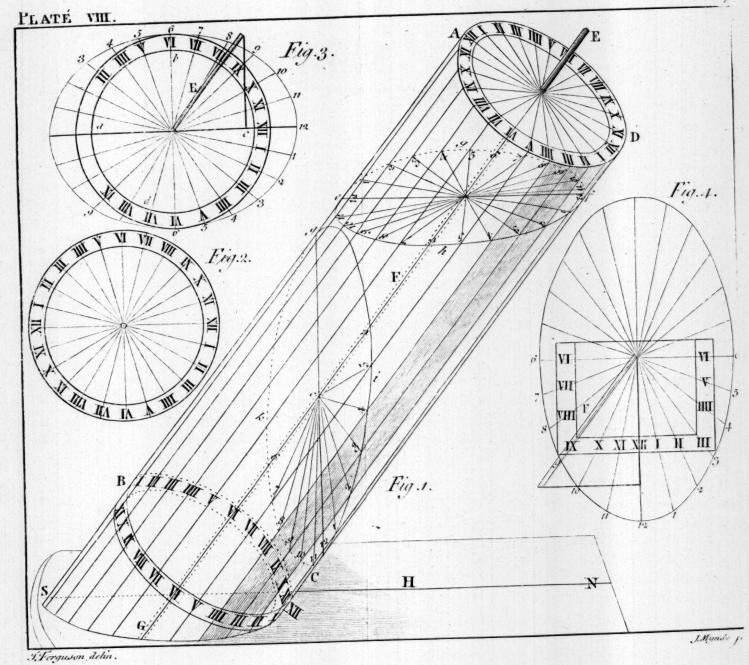
## DIALING.

The universal Dialing Cylinder.

Prefents a cylindrical glass tube, closed at both ends with brass plates, and having a wire or axis EFG fixt in the centers of the brass plates at top and bottom. This tube is fixed to a horizontal board H, and its axis makes an angle with the board equal to the angle of the earth's axis with the horizon of any given place, for which the cylinder is to serve as a dial. And it must be fet with its axis parallel to the axis of the world in that place! the end E pointing to the elevated pole. Or, it may be made to move upon a joint; and then it may be elevated for any particular latitude.

There are 24 straight lines, drawn with a diamond, on the outside of the glass, equidistant from each other, and all of them parallel to the axis. These are the hour-lines: and the hours





are fet to them as in the figure: the XII next B flands for midnight, and the opposite XII, next the board H, flands for mid-day or noon.

The axis being elevated to the latitude of the place, and the foot-board fet truly level, with the black line along its middle in the plane of the meridian, and the end N toward the north; the axis EFG will ferve as a stile or gnomon, and cast a shadow on the hour of the day, among the parallel hour-lines when the sun shines on the machine. For, as the sun's apparent diurnal motion is equable in the heavens, the shadow of the axis will move equably in the tube; and will always fall upon that hour-line which is opposite to the sun, at any given time.

The brass plate AD, at the top, is parallel to the equator, and the axis EFG is perpendicular to it. If right lines be drawn from the center of this plate, to the upper ends of the equidistant parallel lines on the outside of the tube; these right lines will be the hour-lines on the equinoctial dial AD, at 15 degrees distance from each other: and the hour-letters may be set to them as in the figure. Then, as the shadow of the axis within the tube comes on the hour-lines of the tube, it will cover the like hour-lines on the equinoctial plate AD.

If a thin horizontal plate ef be put within the tube, so as its edge may touch the tube all around; and right lines be drawn from the center of that plate to those points of its edge which are cut by the parallel hour-lines on the tube; these right-lines will be the hour-lines of a horizontal dial, for the latitude to which the tube is ele-

vated.

vated. For, as the shadow of the axis comes successively to the hour-lines of the tube, and covers them, it will then cover the like hour-lines on the horizontal plate ef, to which the hours may be set; as in the figure.

If a thin vertical plate g C, be put within the tube, so as to front the meridian or 12 o'clock line thereof, and the edge of this plate touch the tube all around; and then, if right lines be drawn from the center of the plate to those points of its edge which are cut by the parallel hourlines on the tube; these right lines will be the hour-lines of a vertical south dial: and the shadow of the axis will cover them at the same times when it covers those of the tube.

If a thin plate be put within the tube fo, as to decline, or incline, or recline, by any given number of degrees; and right lines be drawn from its center to the hour lines of the tube; these right lines will be the hour-lines of a declining, inclining, or reclining dial, answering to the like number of degrees, for the latitude to which the tube is elevated.

And thus, by this simple machine, all the principles of dialing are made very plain, and evident to the sight. And the axis of the tube (which is parallel to the axis of the world in every latitude to which it is elevated) is the stile or gnomon for all the different kinds of sun-dials.

And lastly, if the axis of the tube be drawn out, with the plates AD, ef, and gC upon it; and set it up in sun-shine, in the same position as they were in the tube; you will have an equinoctial

noctial dial AD, a horizontal dial ef, and a vertical fouth dial gC; on all which, the time of the day will be shewn by the shadow of the axis or gnomon EFG.

Let us now suppose that, instead of a glass tube, ABCD is a cylinder of wood; on which the 24 parallel hour-lines are drawn all around, at equal distances from each other; and that, from the points at top, where these lines end, right lines are drawn toward the center, on the flat furface AD. These right lines will be the hour-lines on an equinoctial dial, for the latitude of the place to which the cylinder is elevated above the horizontal foot or pedestal H; and they are equidiftant from each other, as in Fig. 2. which is a full view of the flat furface or top AD of the cylinder, feen obliquely in Fig. 1. And the axis of the cylinder (which is a straight wire EFG all down its middle) is the stile or gnomon; which is perpendicular to the plane of the equinoctial dial, as the earth's axis is perpendicular to the plane of the equator.

To make a horizontal dial, by the cylinder, for any latitude to which its axis is elevated; draw out the axis and cut the cylinder quite through, as at ebfg, parallel to the horizontal board H, and take off the top part eADfe; and the fection ebfge will be of an elliptical form, as in Fig. 3. Then, from the points of this fection (on the remaining part eBCf) where the parallel lines on the outside of the cylinder meet it, draw right lines to the center of the fection; and they will be the true hour-lines for a horizontal dial, as abcda in Fig. 3. which may be included in a circle drawn on that fection.

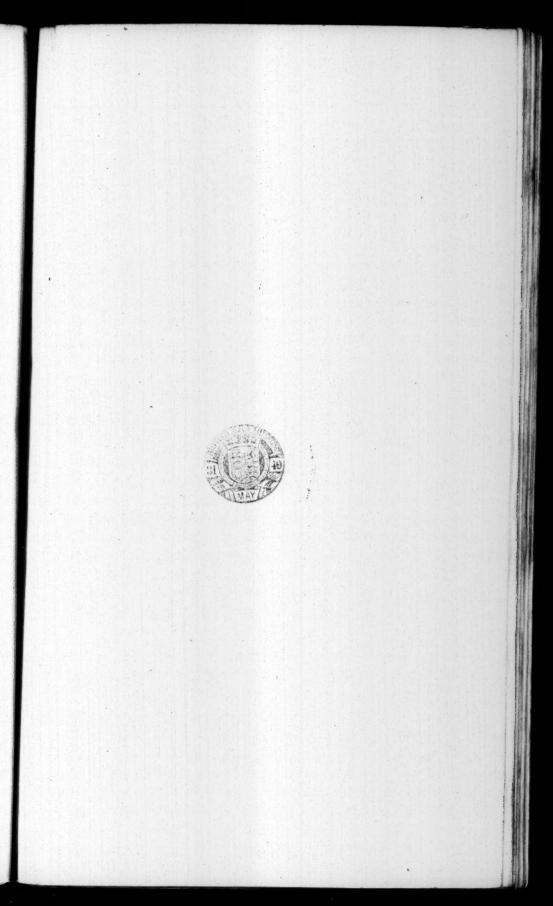
F f Then

Then put the wire into its place again, and it will be a stile for casting a shadow on the time of the day, on that dial. So, E (Fig. 3.) is the stile of the horizontal dial, parallel to the axis of the cylinder.

To make a vertical fouth dial by the cylinder, draw out the axis, and cut the cylinder perpendicularly to the horizontal board H, as at giCkg, beginning at the hour-line (Bge A) of XII, and making the fection at right angles to the line SHN on the horizontal board. Then. take off the upper part g ADC, and the face of the fection thereon will be elliptical, as shewn in Fig. 4. From the points in the edge of this fection, where the parallel hour-lines on the round furface of the cylinder meet it, draw right lines to the center of the fection; and they will be the true hour-lines on a vertical direct fouth dial, for the latitude to which the cylinder was elevated: and will appear as in Fig. 4. on which the vertical dial may be made of a circular shape, or of a square shape as represented in the figure. And F will be its stile parallel to the axis of the cylinder.

And thus, by cutting the cylinder any way, so as its section may either incline, or decline, or recline, by any given number of degrees; and from those points in the edge of the section; where the outside parallel hour-lines meet it, draw right lines to the center of the section; and they will be the true hour-lines, for the like declining, reclining, or inclining dial: and the axis of the cylinder will always be the gnomon or stile of the dial. For, which-ever way the plane of the dial lies, its stile (or the edge thereof

that



that casts the shadow on the hours of the day) must be parallel to the earth's axis, and point toward the elevated pole of the heaven.

To delineate a Sun-Dial on Paper; which, when pasted round a Cylinder of Wood, shall shew the Time of the Day, the Sun's Place in the Ecliptic, and his Altitude, at any Time of Observation. See Plate IX.

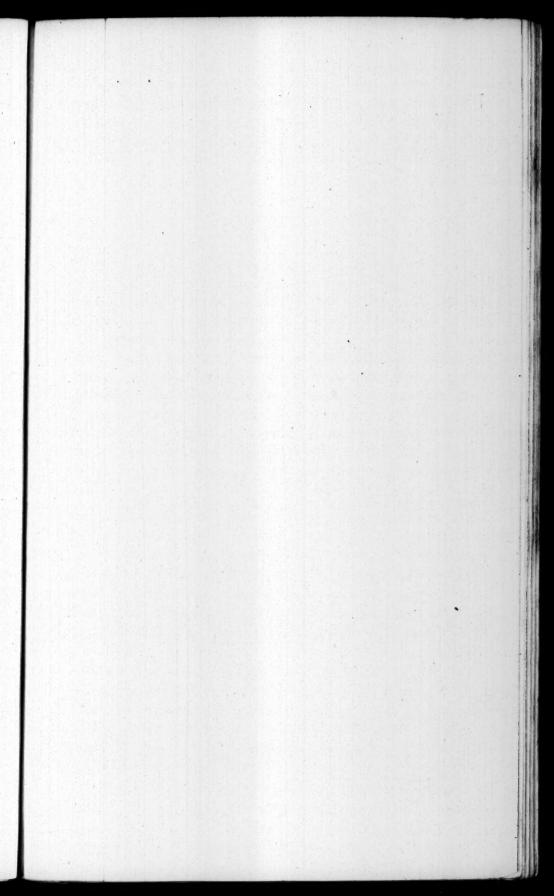
Draw the right line a AB, parallel to the top of the paper; and, with any convenient opening of the compasses, set one foot in the end of the line at a, as a center, and with the other foot defcribe the quadrantal arc AE, and divide it into 90 equal parts or degrees. Draw the right line AC, at right angles to a AB, and touching the quadrant AE at the point A. Then, from the center a, draw right lines through as many degrees of the quadrant as are equal to the fun's altitude at noon, on the longest day of the year, at the place for which the dial is to ferve; which altitude, at London, is 62 degrees: and continue these right lines till they meet the tangent line AC; and, from these points of meeting, draw straight lines across the paper, parallel to the first right line AB, and they will be the parallels of the fun's altitude, in whole degrees, from fun-rife till fun-fet, on all the days of the year .- Thefe parallels of altitude must be drawn out to the right line BD, which must be parallel to AC, and as far from it as is equal to the intended circumference of the cylinder on which the paper is to be pasted, when the dial is drawn upon it.

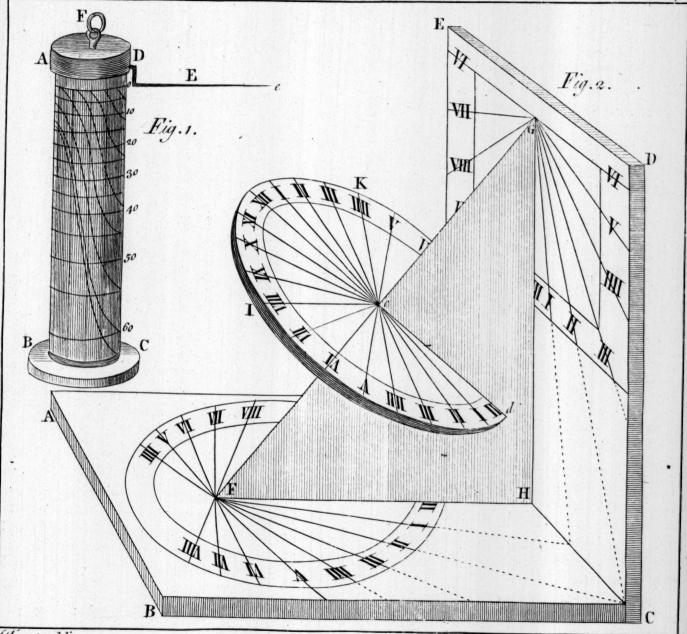
Divide the space between the right lines AC and BD (at top and bottom) into twelve equal F f 2 parts,

parts, for the twelve figns of the ecliptic; and, from mark to mark of these divisions at top and bottom, draw right lines parallel to AC and BD; and place the characters of the 12 signs in these twelve spaces, at the bottom, as in the sigure: beginning with be or Capricorn, and ending with or Pisces. The spaces including the signs should be divided by parallel lines into halves; and if the breadth will admit of it without confusion, into quarters also.

At the top of the dial, make a scale of the months and days of the year, so as the days may stand over the sun's place for each of them in the signs of the ecliptic. The sun's place, for every day of the year, may be sound by any common ephemeris: and here it will be best to make use of an ephemeris for the second year after leap-year; as the nearest mean for the sun's place on the days of the leap-year, and on those of the sirft, second, and third year after.

Compute the fun's altitude for every hour (in the latitude of your place) when he is in the beginning, middle, and end of each fign of the ecliptic; his altitude at the end of each fign being the fame as at the beginning of the next. And, in the upright parallel lines, at the beginning and middle of each fign, make marks for these computed altitudes among the horizontal parallels of altitude, reckoning them downward, according to the order of the numeral figures set to them at the right hand, answering to the like divisions of the quadrant at the left. And, through these marks, draw the curve hour-lines, and set the hours to them, as in the figure, reckoning the forenoon hours downward, and





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the afternoon hours upward.—The fun's altitude should also be computed for the half hours; and the quarter-lines may be drawn, very nearly in their proper places, by estimation and accuracy of the eye. Then, cut off the paper at the left hand, on which the quadrant was drawn, close by the right line AC, and all the paper at the right hand close by the right line BD; and cut it also close by the top and bottom horizontal lines; and it will be sit for pasting round the cylinder.

This cylinder is represented in miniature by Fig. 1. PLATE X. It should be hollow, to hold the stile DE when it is not used. The crooked end of the stile is put into a hole in the top AD of the cylinder; and the top goes on tightish, but must be made to turn round on the cylinder, like the lid of a paper snuff-box. The stile must stand straight out, perpendicular to the side of the cylinder, just over the right line AB in PLATE IX, where the parallels of the sun's altitude begin; and the length of the stile, or distance of its point e from the cylinder, must be equal to the radius a A of the quadrant AE in PLATE IX,

## The method of using this dial is as follows.

Place the horizontal foot BC of the cylinder on a level table where the fun shines, and turn the top AD till the stile stands just over the day of the then present month. Then turn the cylinder about on the table, till the shadow of the stile salls upon it, parallel to those upright lines which divide the signs; that is, till the shadow be parallel to a supposed axis in the middle of the cylinder: and then, the point, or lowest end

of the shadow, will fall upon the time of the day, as it is before or after noon, among the curve hourlines; and will shew the suh's altitude at that time, among the cross parallels of his altitude, which go round the cylinder: and, at the same time, it will shew in what sign of the ecliptic the sun then is, and you may very nearly guess at the degree of the sign, by estimation of the eye.

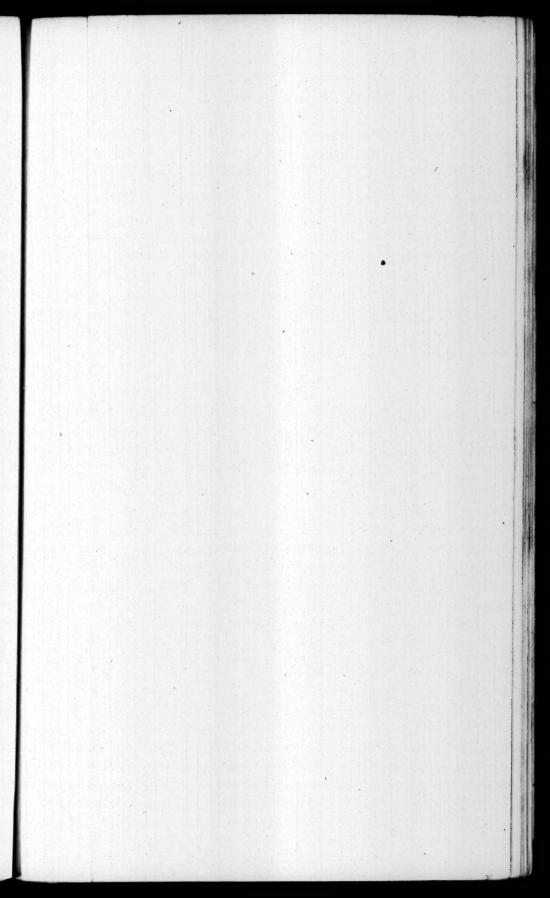
The ninth plate, on which this dial is drawn, may be cut out of the book, and pasted round a cylinder whose length is 6 inches and 6 tenths of an inch below the n oveable top; and its diameter 2 inches and 24 hundred parts of an inch.—Or, I suppose the copper-plate prints of it may be had of the booksellers in London. But it will only do for London, and other places of the same latitude.

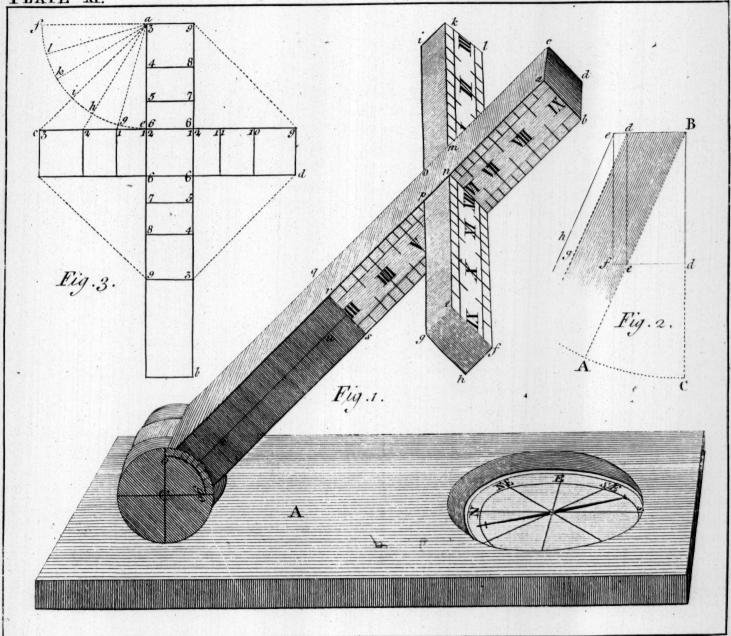
When a level table cannot be had, the dial may be hung by the ring F at the top. And when it is not used, the wire that serves for a stile may be drawn out, and put up within the cylinder; and the machine carried in the pocket.

To make three Sun-dials upon three different Planes, fo as they may all snew the Time of the Day by one Gnomon.

On the flat board ABC, describe a horizontal dial, according to any of the rules laid down in the Lecture on Dialing; and to it fix its gnomon FGH, the edge of the shadow from the side FG being that which shews the time of the day.

To this horizontal or flat board, join the upright board EDC, touching the edge GH of the gnomon. Then, making the top of the gnomon





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gnomon at G the center of the vertical fouth dial, describe a south dial on the board EDC.

Lastly, on a circular plate IK describe an equinoctial dial, all the hours of which dial are equidistant from each other, and making a slit cd in that dial, from its edge to its center, in the XII o'clock line; put the said dial perpendicularly on the gnomon FG, as far as the slit will admit of; and the triple dial will be finished; the same gnomon serving all the three, and shewing the same time of the day on each of them.

## An universal Dial on a plain Cross.

This dial is represented by Fig. 1. of PLATE XI, and is moveable on a joint C, for elevating it to any given latitude, on the quadrant  $C \circ 90$ , as it stands upon the horizontal board A. The arms of the cross stand at right angles to the middle part; and the top of it from a to n, is of equal length with either of the arms n e or m k.

Having set the middle line tu to the latitude of your place, on the quadrant, the board A level, and the point N northward by the needle; the plane of the cross will be parallel to the plane of the equator; and the machine will be rectified.

Then, from III o'clock in the morning, till VI, the upper edge kl of the arm io will cast a shadow on the time of the day on the side of the arm cm: from VI till IX the lower edge i of the arm io will cast a shadow on the hours on the side oq. From IX in the morning to XII at noon, the edge ab of the top part an will cast a shadow on the hours on the arm nef: from XII

to III in the afternoon, the edge cd of the top part will cast a shadow on the hours on the arm klm: from III to VI in the evening, the edge gb will cast a shadow on the hours on the part ps; and from VI till IX, the shadow of the edge ef will shew the time on the top part an.

The breadth of each part ab, ef, &c. must be so great as never to let the shadow fall quite without the part or arm on which the hours are marked, when the sun is at his greatest declination from the equator.

To determine the breadth of the sides of the arms which contain the hours, so as to be in just proportion to their length; make an angle ABC (Fig. 2.) of  $23\frac{1}{2}$  degrees, which is equal to the sun's greatest declination; and suppose the length of each arm, from the side of the long middle part, and also the length of the top part above the arms, to be equal to Bd.

Then, as the edges of the shadow from each of the arms, will be parallel to Be, making an angle of  $23\frac{\pi}{2}$  degrees with the side Bd of the arm when the sun's declination is  $23\frac{\pi}{2}$  degrees; it is plain, that if the length of the arm be Bd, the least breadth that it can have, to keep the edge Be of the shadow Begd from going off the side of the arm de before it comes to the end ed thereof, must be equal to ed or dB. But in order to keep the shadow within the quarter divisions of the hours, when it comes near the end of the arm, the breadth thereof should be still greater, so as to be almost doubled, on account of the distance between the tips of the arms.

To place the hours right on the arms, take the following method:

Lay down the cross a b c d (Fig. 3.) on a sheet of paper; and with a black lead pencil, held close to it, draw its shape and size on the paper. Then, taking the length a e in your compasses, and setting one foot in the corner a, with the other foot describe the quadrantal arc e f.—
Divide this arc into six equal parts, and through the division marks draw right lines a g, a h, &c. continuing three of them to the arm ce, which are all that can fall upon it; and they will meet the arm in these points through which the lines that divide the hours from each other (as in Fig. 1.) are to be drawn right across it.

Divide each arm, for the three hours it contains, in the same manner; and set the hours to their proper places (on the sides of the arms) as they are marked in Fig. 3. Each of the hour spaces should be divided into sour equal parts, for the half hours and quarters, in the quadrant ef; and right lines should be drawn through these division marks in the quadrant, to the arms of the cross, in order to determine the places thereon where the sub-divisions of the hours must be marked.

This is a very simple kind of universal dial; it is very easily made, and will have a pretty uncommon appearance in a garden.—I have seen a dial of this fort, but never saw one of the kind that follows:

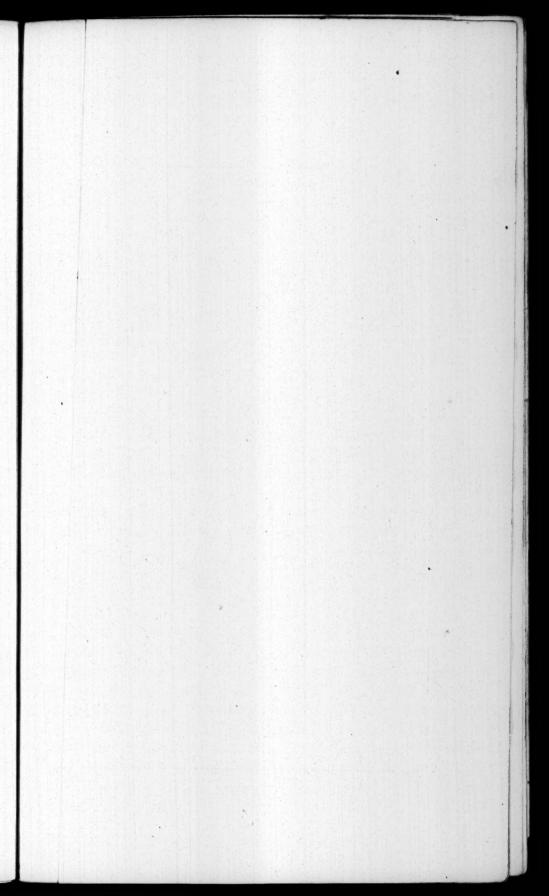
An universal Dial, shewing the Hours of the Day by a terrestrial Globe, and by the Shadows of several Gnomons at the same Time: together with all the Places of the Earth which are then enlightened by the Sun; and those to which the Sun is then Rising, or on the Meridian, or Setting.

This dial (See PLATE XII.) is made of a thick square piece of wood, or hollow metal. The fides are cut into femicircular hollows, in which the hours are placed; the stile of each hollow coming out from the bottom thereof, as far as the ends of the hollows project. corners are cut out into angles, in the infides of which, the hours are also marked; and the edge of the end of each fide of the angle ferves as a ftile for casting a shadow on the hours marked on the other fide.

In the middle of the uppermost side or plane, there is an equinoctial dial; in the center whereof, an upright wire is fixt, for casting a shadow on the hours of that dial, and supporting a small terrestrial globe on its top.

The whole dial flands on a pillar, in the middle of a round horizontal board, in which there is a compass and magnetic needle, for placing the meridian stile toward the fouth. pillar has a joint with a quadrant upon it, divided into 90 degrees (supposed to be hid from fight under the dial in the figure) for fetting it to the latitude of any given place; the fame way as already described in the dial on the cross.

The equator of the globe is divided into 24 equal parts, and the hours are laid down upon it at



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at these parts. The time of the day may be known by these hours, when the sun shines upon the globe.

To rectify and use this dial, set it on a level table, or sole of a window, where the sun shines, placing the meridian stile due south, by means of the needle; which will be, when the needle points as far from the north sleur de-lis toward the west, as it declines westward, at your place. Then bend the pillar in the joint, till the black line on the pillar comes to the latitude of your place in the quadrant.

The machine being thus rectified, the plane of its dial-part will be parallel to the equator, the wire or axis that supports the globe will be parallel to the earth's axis, and the north pole of the globle will point toward the north pole of the heaven.

The same hour will then be shewn in several of the hollows, by the ends of the shadows of their respective stiles. The axis of the globe will cast a shadow on the same hour of the day, in the equinoctial dial, in the center of which it is placed, from the 20th of March to the 22d of September; and, if the meridian of your place on the globe be fet even with the meridian stile, all the parts of the globe that the fun shines upon, will answer to those places of the real earth which are then enlightened by the fun. The places where the shade is just coming upon the globe, answer all to those places of the earth to which the fun is then fetting; as the places where it is going off, and the light coming on, answer to all those places of the earth where the fun is then rifing. And lastly, if the hour of VI

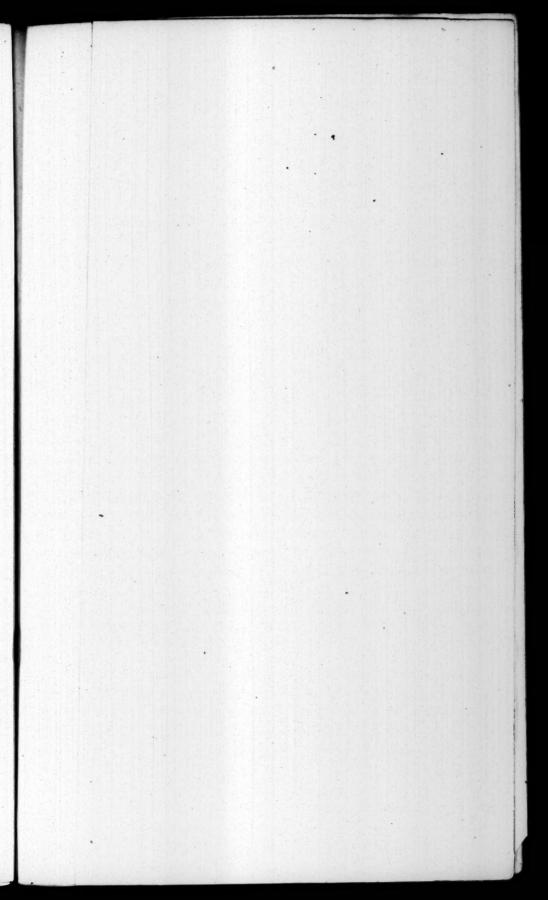
be marked on the equator in the meridian of your place (as it is marked on the meridian of London in the figure) the division of the light and shade on the globe will shew the time of the day.

The northern stile of the dial (opposite to the fouthern or meridian one) is hid from fight in the figure, by the axis of the globe. The hours in the hollow to which that stile belongs, are also supposed to be hid by the oblique view of the figure: but they are the fame as the hours in the front hollow. Those also in the right and left hand femicircular hollows are mostly hid from fight; and fo also are all those on the fides next the eye of the four acute angles.

The confruction of this dial is as follows. See PLATE XIII.

On a thick square piece of wood, or metal, draw the lines a c and b d, as far from each other as you intend for the thickness of the stile abcd, and in the fame manner, draw the like thickness of the other three stiles, efgb, iklm, and nopq, all standing outright as from the center.

With any convenient opening of the compasses, as a A (so as to leave proper strength of stuff when K I is equal to a A) set one foot in a, as a center, and with the other foot describe the quadrantal arc Ac. Then, without altering the compasses, set one foot in b as a winter, and with the other foot describe the quadrant dB. All the other quadrants in the figure must be described in the same manner, and with



the same opening of the compasses, on their centers e, f; i, k; and n, o: and each quadrant divided into 6 equal parts, for so many hours, as in the figure; each of which parts must be sub-divided into 4, for the half hours and quarters.

At equal distances from each corner, draw the right lines Ip and Kp, Lq and Mq, Nr and Or, Ps and Qs; to form the four angular hollows IpK, LqM, NrO, and PsQ: making the distances between the tips of these hollows, as IK, LM, NO, and PQ, each equal to the radius of the quadrants; and leaving sufficient room within the angular points, p, q, r, and s, for the equinoctial circle in the middle.

To divide the infides of these angles properly for the hour-spaces thereon, take the following method:

Set one foot of the compasses in the point I, as a center; and open the other to K, and with that opening, describe the arc Kt: then, without altering the compasses, set one foot in K, and with the other foot describe the arc It. Divide each of these arcs, from I and K to their intersection at t, into four equal parts; and from their centers I and K, through the points of division, draw the right lines I 3, I 4, I 5, 16, 17; and K2, K1, K12, K11; and they will meet the fides Kp and Ip of the angle Ip Kwhere the hours thereon must be placed. And these hour-spaces in the arcs must be sub-divided into four equal parts, for the half hours and quarters.-Do the like for the other three angles, and draw the dotted lines, and fet the hours hours in the infides where those lines meet them, as in the figure: and the like hour-lines will be parallel to each other in all the quadrants and in all the angles.

Mark points for all these hours, on the upper fide and cut out all the angular hollows, and the quadrantal ones quite through the places where their four gnomons must stand; and lay down the hours on their insides, as in Plate XII, and then set in their four gnomons, which must be as broad as the dial is thick; and this breadth and thickness must be large enough to keep the shadows of the gnomons from ever falling quite out at the sides of the hollows, even when the sun's declination is at the greatest.

Lastly, draw the equinoctial dial in the middle, all the hours of which are equidistant from each other; and the dial will be finished.

As the sun goes round, the broad end of the shadow of the stile abcd will shew the hours in the quadrant Ac, from sun rise till VI in the morning; the shadow from the end M will shew the hours on the side Lq from V to IX in the morning; the shadow of the stile efgb in the quadrant Dg (in the long days) will shew the hours from sun-rise till VI in the morning; and the shadow of the end N will shew the morning hours, on the side Or, from III to VII.

Just as the shadow of the northern stile abcd goes off the quadrant Ac, the shadow of the southern stile iklm begins to sall within the quadrant Fl, at VI in the morning; and shews the time, in that quadrant, from VI till XII at noon:

noon; and from noon till VI in the evening in the quadrant mE. And the shadow of the end O shews the time from XI in the forenoon till III in the afternoon, on the side rN; as the shadow of the end P shews the time from IX in the morning till I o'clock in the afternoon, on the side Qs.

At noon, when the shadow of the eastern stile efgh goes off the quadrant hC (in which it shewed the time from VI in the morning till noon, as it did in the quadrant gD from surrise till VI in the morning) the shadow of the western stile nopq begins to enter the quadrant Hp; and shews the hours thereon from XII at noon till VI in the evening; and after that till sunset, in the quadrant qG: and the end Q casts a shadow on the side Ps from V in the evening till IX at night, if the sun be not set before that time.

The shadow of the end I shews the time on the side Kp from III till VII in the afternoon; and the shadow of the stile abcd shews the time from VI in the evening till the sun sets.

The shadow of the wright central wire, that supports the globe at top, shews the time of the day, in the middle or equinoctial dial, all the summer half year, when the sun is on the north side of the equator.

In this Supplement to my book of Lectures, all the machines that I have added to my apparatus, fince that book was printed, are defcribed, excepting two; one of which is a model

of a mill for fawing timber, and the other is a model of the great engine at London-bridge, for raising water. And my reasons for leaving them out are as follow:

First, I found it impossible to make such a drawing of the saw-mill as could be understood; because, in whatever view it be taken, a great many parts of it hid others from sight. And, in order to shew it in my Lectures, I am obliged to turn it into all manner of positions.

Secondly, Because any person who looks on Fig. 1. of PLATE XII in the book, and reads the account of it in the fifth Lecture therein, will be able to form a very good idea of the London-bridge engine, which has only two wheels and two trundles more than there are in Mr. Aldersea's engine, from which the said figure was taken.



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